TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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VARIATIONS IN MARITIME VESSEL ALERT SYSTEMS

Master of Science Thesis

Examiners: Prof. Matti Vilkko & Assistant Prof. David Hästbacka
Examiners and topic approved by the Faculty Council of the Faculty of the Engineering Sciences on 3 October 2018

ABSTRACT

EIKKA POLLARI: Variations in Maritime Vessel Alert Systems
Tampere University of Technology
Master of Science Thesis, 71 pages, 6 Appendix pages
December 2018
Master's Degree Programme in Automation Technology
Major: Process Automation
Examiners: Professor Matti Vilkko, Assistant Professor David Hästbacka

Keywords: maritime automation, alerts, vessel alert system, text classification

The maritime industry is continuously raising the level of automation on board vessels, the eventual goal being to introduce remotely operated and autonomous commercial vessels in the near future. Due to this development, more intelligent vessel alert systems are needed, as they are required to provide more detailed information and sophisticated alarm management functions. However, developing an intelligent alert system customisable for various vessel types and/or implemented as a retrofit installation is a challenging task. This thesis aims to help in that work.

The objective of this thesis is summarised into three goals. The first one was to find out what kind of challenges the variations in alerts and alert systems between various vessels and vessel types cause for developing an intelligent alert system customisable for variable types of vessels. Based on the literature review and the carried out interview study, the variations complicate the required grouping of alerts when designing various alarm management functions: due to differently formed alerts, grouping is automatically done very difficult and manually very time-consuming and demanding.

The second goal was to suggest a development roadmap for the intelligent alert system so that the vessel types with less variations come first. According to the interviews, the amount of variations can be derived from the complexity, i.e. the operational purpose and automation level, of the vessel type and vessel. Thus, the simplest vessel types, such as tugs, oil tankers and containers were suggested to be focused on first. The interviews suggested also that the simplest vessel types should be forgotten and the development should be started from a bit more complex vessels, e.g. from off-shore service vessels.

The third goal was to provide examples of how to take the variations into account when developing the intelligent alert system. For this, an Excel tool to categorise automatically differently formed alert signals of signal lists was developed by studying and utilising real-life alert lists and by applying methods of text classification. Also, grouping methods of the SFI Group System were utilised.

In tests the developed signal list categoriser proved to be effective and easily updatable for better accuracy and more comprehensive categorising capability. Thus, the goals set for this thesis were reached. If more detailed data about the variations in alerts and alert systems were wanted, a very large amount of alert list data should be gathered and statistically analysed. However, that would be a very challenging study to accomplish due to the amount of needed data and the difficulty to acquire it. The developed signal list categoriser could be further developed e.g. by analysing more alert lists and applying various, sophisticated machine learning algorithms utilised in text analytics.

TIIVISTELMÄ

EIKKA POLLARI: Vaihtelevuudet laivojen hälytysjärjestelmissä
Tampereen teknillinen yliopisto
Diplomityö, 71 sivua, 6 liitesivua
Joulukuu 2018
Automaatiotekniikan diplomi-insinöörin tutkinto-ohjelma
Pääaine: Prosessien hallinta
Tarkastajat: Professori Matti Vilkko, Assistant Professor David Hästbacka

Avainsanat: laiva-automaatio, hälytys, hälytysjärjestelmä, tekstin luokittelu

Meriteollisuuden lähitulevaisuuden tavoite on lanseerata autonomisia ja etäohjattavia kaupallisia aluksia. Siksi merenkulussa tarvitaan älykkäämpiä järjestelmiä tarjoamaan käyttäjilleen tarkempaa ja yksityiskohtaisempaa tietoa. Älykkään hälytysjärjestelmän kehittäminen on kuitenkin haasteellista, mikäli sen halutaan olevan sopiva mahdollisimman monelle alustyypille ja toteutettavissa jälkiasennuksena jo käytössä oleviin aluksiin. Tämän diplomityön tarkoitus on tuottaa tietoa ja menetelmiä auttamaan tätä kehitystyötä.

Diplomityölle asetettiin kolme tavoitetta. Ensimmäisenä oli selvittää, minkälaisia haasteita hälytysten ja hälytysjärjestelmien vaihtelevuudet eri alustyyppien ja alusten välillä aiheuttavat eri alustyypeille soveltuvan, älykkään hälytysjärjestelmän kehittämiselle. Kirjallisuusselvityksen ja haastattelujen perusteella vaihtelevuudet monimutkaistavat suunnittelemisessa tarvittavaa hälytysten luokittelemista: eri tavoin muotoiltujen hälytysten luokitteleminen automaattisesti on vaikeaa ja manuaalisesti erittäin työlästä.

Toinen tavoite oli ehdottaa alustyyppejä, joihin älykkään hälytysjärjestelmän kehittämisessä tulisi aluksi keskittyä, jotta vaihtelevuuksien aiheuttamat hankaluudet olisivat mahdollisimman pieniä. Haastattelujen perusteella voidaan yleistää, että mitä yksinkertaisempi laivatyyppi on, sitä vähemmän sen alusten hälytykset keskenään eroavat. Tämän perusteella alkuun ehdotettiin yksinkertaisimpia aluksia, kuten hinaajia, öljytankkereita ja konttialuksia. Vaihtoehtoisessa lähestymistavassa ehdotettiin ensin keskityttävän hieman monimutkaisempiin laivoihin, joissa korkeamman automaatioasteen vuoksi älykkäästä hälytysjärjestelmästä olisi selvästi enemmän hyötyä kuin yksinkertaisimmissa aluksissa. Esimerkki tällaisesta alustyypistä on offshore-tukialukset.

Työn kolmas tavoite oli antaa esimerkkejä, kuinka vaihtelevuuksien aiheuttamat haasteet voitaisiin voittaa. Tätä varten kehitettiin Excel-työkalu, joka luokittelee automaattisesti hälytyslistojen hälytykset ennalta määrättyihin kategorioihin. Työkalun kehittämisessä sovellettiin tekstin luokittelu- ja SFI Group Systemin ryhmittelymetodeja, lisäksi hyödynnettiin eri tosielämän hälytyslistoja tutkimalla saatuja tietoja.

Käyttökokeissa kehitetty Excel-työkalu osoittautui tehokkaaksi. Käyttäjän on myös helppo päivittää sitä kattavampien luokittelutulosten saavuttamiseksi. Tämän perusteella diplomityön tavoitteet saavutettiin. Mikäli vaihtelevuuksista haluttaisiin tarkempaa tietoa, täytyisi analysoida tilastollisesti valtava määrä hälytyslistadataa. Tällainen tutkimus olisi kuitenkin erittäin haasteellista toteuttaa, sillä tarpeellista aineistoa on hankala saada. Kehitettyä Excel-työkalua voitaisiin parantaa esimerkiksi hyödyntämällä suurempaa määrää hälytyslistadataa ja soveltamalla tekstin luokittelussa käytettyjä, kehittyneitä koneoppimisalgoritmeja.

PREFACE AND ACKNOWLEDGEMENTS

This thesis was done for Rolls-Royce Oy Ab between November 2017 and November 2018. As the process was occasionally difficult and it grew longer than anticipated, finishing feels particularly good. I am grateful for the provided opportunity.

Firstly, I want to express my great gratitude for my supervisor Anna-Maria Blomster from Rolls-Royce for offering this topic and guiding and supporting me all the way through it. Big thanks from Rolls-Royce also to Jani Aaltonen for co-supervision and all the educating discussions familiarising me with the maritime industry, to Arto Teinilä for enabling this thesis for his part, and to all the interviewees.

From Tampere University of Technology I want to thank Professor Matti Vilkko and Assistant Professor David Hästbacka for examining this thesis and giving me valuable academic guidance and feedback. I am also thankful for all the teaching personnel and fellow students I have been dealing with during my years at TUT.

To my family and friends I am ever-grateful for the support they have given me throughout my studies and life. And last but certainly not least, I want to thank Pirita for all her encouragement, support and understanding in my everyday life.

Turku, 12.11.2018

Eikka Pollari

CONTENTS

LIST OF ABBREVIATIONS AND SYMBOLS

ANSI	American National Standards Institute
ASM	Abnormal Situations Management
BAM	Bridge Alert Management
BNWAS	Bridge Navigational Watch Alarms System
CAI	Code on Alerts and Indicators
CS	Classification Society
DCS	Distributed Control System
DP	Dynamic Positioning
EAS	Extension Alarm System
EEMUA	Engineering Equipment and Materials Users Association
FO	Fuel Oil
FPSO	Floating Production, Storage and Offload unit
HT	High Temperature
HVAC	Heating, Ventilation and Air-Conditioning
I/O	Input/Output
IACS	International Association of Classification Societies
IAS	Integrated Automation System
ICMS	Integrated Control and Monitor System
IMO	International Maritime Organization
ISA	International Society of Automation
LNG	Liquefied Natural Gas
LO	Lubrication Oil
LPG	Liquefied Petroleum Gas
LT	Low Temperature
MSC	Maritime Safety Committee
OSV	Off-shore Service Vessel
PLC	Programmable Logic Controller
Ro-Ro	Roll-on Roll-off
SCADA	Supervisory Control and Data Acquisition
SCR	Selective Catalytic Reduction
SOLAS	Safety of Life at Sea
ULCC	Ultra Large Crude Carrier
UN	The United Nations
VBA	Visual Basic for Applications
VLCC	Very Large Crude Carrier

dwt	Deadweight tonnage. The difference between the displacement and the mass of empty vessel at any given draught. Measures vessel's ability to carry cargo, crew, passengers, fuel, ballast water, etc.
knot	Speed of one nautical mile per hour, equal to 1.852 *km/h*

1. INTRODUCTION

An alert[1] system has an essential role in the safe and efficient operation of a maritime vessel. Its functions can be divided into a primary and a secondary, the first one is to warn the operator about an abnormal situation and the latter one is to serve as an alarm and event log [1]. With these functions the alert system helps the crews' work to operate vessels safely and efficiently and also reduces the need of manpower on board, as various distributed systems do not need to be supervised locally.

The first alert systems were basically panel boards into which sensors and other process equipment were connected with analogue signals. The big change came with digital technologies, such as distributed control systems (DCSs), Supervisory Control and Data Acquisition (SCADA) systems, microprocessors and programmable logic controllers (PLCs), in the 1980's. Since then it has been both easy and practically costless to add new signals in an alert system. That did not come without any problems, as systems grew rapidly bigger and bigger also more and more useless signals and functions were added in them. Consequently the focus is nowadays on developing more intelligent alert systems with better alarm management practises to take over control of the expansion. [2][3]

In the maritime industry designing a new system can be challenging. There are a broad range of different maritime vessel types, from smaller vessels like fishing ships and tugs to huge crafts like oil tankers and luxury cruise ships, which means boundary conditions and requirements for the alert systems and their design can variate considerably. Also, the International Maritime Organization (IMO), various classification societies (CSs) and flag states have their own safety regulations for alert systems to meet. That makes it difficult to build an alert system that would be universal and applicable for many different vessel types. One thing this thesis aims to do is to give knowledge and methods for helping that work.

This chapter consists of five sub-chapters. The motivation for this thesis work is explained in the first of them and the second one presents the state of the art regarding the alert systems. These are followed by the introduction of the research questions and goals and the used research methodologies in the third and the fourth sub-chapters. In the last sub-chapter the structure of this thesis is gone through.

[1] In the IMO's Codes, alerts are categorised into four priority classes: emergency alarms, alarms, warnings and cautions. Word 'alert' is an umbrella term covering all of the four priorities and is thus preferred over word 'alarm' throughout this thesis.

1.1 Motivation

In the process industry plant operators are facing a problem called *alarm flooding*, a situation during which the alert rate is in such a high level that the operators cannot manage the occurred alerts quickly and precisely enough [4]. In maritime vessels this kind of an event is common especially when ships are having blackouts, i.e. loss of electric power due to generator failure, for example. Alarm flooding descends from the rapidly increased amount of alarms in the alert systems, which is caused by things like significant growth of plants, bad design and difficulties in adopting new alert management methodologies in large-scale applications [5]. In addition, digitalisation and digital control technologies have had their role in this.

As said, the maritime industry is facing same kind of problems with alarm flooding and alert management as the process industry [6]. At the same time the industry is going towards more and more automated vessels – eventually the goal is to introduce autonomous and remotely operated vessels in the near future [7][8]. This development naturally sets very high demands on the vessel automation systems, as at the same time more intelligence is needed and a lot of more inputs and outputs (I/Os) are added in them. The vessel alert systems get their share of the higher requirements too as, for instance, the information they provide need to be more specific and detailed. This leads to a need of developing intelligent vessel alert systems.

In this thesis, an intelligent alert system refers to a system fulfilling the targets of the state of the art alert system design and alarm management guidelines. Such a system contains sophisticated alarm management and rationalising functions, such as advanced alert filtering, grouping and prioritisation. With these functions the alert system, for instance, provides the right information at the right time, alarms principally only root causes, enables automatic interpretations and diagnosis of the vessel's overall condition and provides support for proactive interventions.

The development of an intelligent alert system is challenging, especially if it is to be customisable for many different vessels and vessel types and installed as a retrofit in an existing vessel. In this case a retrofit installation means that an existing alert system is replaced with a new one but existing cabling, cabinets and thus basic functionality are preserved [9]. One challenge in this case is the variations between different system suppliers, vessel types and vessels. For an intelligent alert system to be customisable for many different vessels and vessel types, it has to be able utilise this varying alert data from various sources – meaning these variations need to be taken into account. The problem is that it is not clearly known in which way and how much alerts and alert systems between different vessels, vessel types and manufacturers differ. This thesis aims to find answers for those questions, and based on the resulted answers, examples are given how the customisation work could be done.

1.2 State of the art

It seems that there is not much of specific academic research done in the field of maritime automation and alert systems, or at least references are very difficult to find. Besides the little academic research work, also the development of the alert systems in the maritime industry has been slower than, for instance, in the process industry. This is partly due to smaller competition and partly to the many standards and regulations set by the IMO and different classification societies, like the Lloyd's Register, Det Norske Veritas and Germanischer Lloyd, Bureau Veritas and American Bureau of Shipping, in order to ensure the high reliability of the automation. In addition, the conservativeness of the industry is seen slowing down the progress. [10][11]

The process industry, however, started to tackle the problems with alerts and alert systems seriously in 1994 when Honeywell and its nine collaborator companies first formatted the Abnormal Situations Management (ASM) Joint R&D Consortium and then applied for and won funding from the National Institute of Standards and Technology to develop collaborative decision support technologies. Since then, the ASM Consortium has completed several research programmes producing a number of approaches, technologies and learnings to help to solve the problems with alerts. [12] In addition, since its foundation, the ASM Consortium has published tens of white papers and three guidelines, including the title 'Effective Alarm Management Practises' published in 2009 [13][14].

Besides the ASM Consortium, both academic and other industrial institutes have studied alert systems and developed their own solutions and technologies for things like alarm flooding and alarm management systems. Several design guidelines and standards have been introduced to help reducing the number of alerts, rationalising the systems and generally improving alert systems' efficiencies. The two most widely spread and important ones of these are 'EEMUA 191' and 'ANSI/ISA-18.2'. [5]

Engineering Equipment and Materials User's Association (EEMUA) published first version of its guideline *EEMUA 191, Alarm Systems – A Guide to Design, Management and Procurement* in 1999. Since then, it has been updated twice, the second edition being published in 2007 and the third in 2013. It serves as a guideline to good practise of alert management and alert rationalising and has become since its publication globally considered as the *de facto* standard on intelligent alarm management. EEMUA 191 discusses the classification of alert messages and the influence of alert rate on the operator performance. [15][16]

The International Society of Automation's (ISA) and American National Standards Institute's (ANSI) standard *ANSI/ISA-18.2, Management of Alarm Systems for the Process Industries*, was first published in 2009 and later updated in its second edition in 2016. It is a standard for alert systems that are part of modern control systems, like DCSs, SCADA systems and PLCs, and focuses on work process requirements and recommendations for effective alarm management [17][18]. Like EEMUA 191, it provides guidance helping users design, implement and maintain an alert system [19].

Academic research work to make alert systems more intelligent and rational e.g. by reducing the number of alerts has been done widely in the past decade. Most of the studies have aimed to reduce number of alarm floods and to make the occurred floods less severe. For instance, techniques and strategies such as dynamic alarm handling by dynamically changing alarm limits [20], recognition and removal of redundant alarms with data mining [21], reduction of number of alarms by grouping alarm messages with a common root cause by combining alarm logs and plant connectivity [22] and alarm prioritisation based on alarm severity calculated with fuzzy-logic rules [23] have been introduced.

Another research topic has been the prediction and prevention of alarm floods. Some algorithms have been developed for comparing incoming alarm sequences with alarm floods in the historical database to find similarities and to warn about possible alarm floods. Examples of these algorithms are a dynamic time warping algorithm used by Ahmed et al. [24], a modified Smith-Waterman algorithm developed by Cheng et al. [25] and a local alignment algorithm based on the basic local alignment search tool by Hu et al. [4].

Even though the studies presented in the preceding text have been done on the field of process industry, like chemical refineries and power plants, they can be considered relevant also for the maritime industry – after all maritime vessels are in many ways similar to, for instance, engine power plants as they have more or less the same systems and equipment in them. Certainly vessels have specific systems like Dynamic Positioning (DP) system generating a lot of alerts that do not exist in the process industrial plants, but yet alerts are alerts and same design guidelines and management methodologies apply. For instance, many of the articles dealing with alarm flooding introduce methods and algorithms for alert grouping. Some of those might well be utilisable when dealing with the challenges caused by alert variations. However, as said, the amount of academic research done in the field of maritime alert systems seems to be small.

1.3 Research questions and goals of the thesis

The purpose of this thesis is to find out what kind of variations there are in alerts and alert systems between different maritime vessel types and vessels. Also, the variations between maritime alert systems of different suppliers are studied. These variations are analysed to reach the first goal of this thesis, which is to find out what kind of challenges and limitations the variations cause for developing an intelligent alert system that is customisable for variable vessel types. This knowledge acts as a baseline for the rest of the goals of this thesis. The second goal is to suggest which vessel types should be first focused on when developing an intelligent alert system. This is to be done from the perspective of variations of existing alerts and effort needed to customise the alert system. In other words, the goal is to propose a reasonable roadmap for the development work for the different vessel types. The third and final goal is to provide examples how to customise an intelligent vessel alert system for various maritime vessels and vessel types.

The goals set in the previous paragraph are verbalized into the following three research questions:

1. How do alerts and alert systems variate between different maritime vessel types, vessels and alert system suppliers' products?
2. What kind of challenges do variations between different existing vessel alerts and alert systems cause when developing an intelligent vessel alert system for various vessel types?
3. In which ways could a vessel alert system be optimally customised for various vessel types with respect to needed amount of work?

To limit the research questions and the scope of this thesis, only the most common vessel types are considered.

In order to answer the first question people with operational experience in the maritime vessels are interviewed and also some alert signal lists are compared with each other to get some ideas. The purpose is to get some basic knowledge of the variations which could be utilised in the later parts of this work. Variations in the following are studied:

- How do the amount of alert signals and alert rate variate between various vessel types and vessels?
- How do alert signal tagging for the same types of equipment variate between different vessel types and vessels and in alert system of different suppliers?
- How do alert signal descriptions for the same alerts variate between different vessel types and vessels and in alert systems of different suppliers?

In addition to the three points above, it is studied how convergent different vessel types are regarding alerts. In other words, the purpose is to find out if there are, on the one hand, vessel types in which alerts are normally rather similar and, on the other hand, types in which they variate extremely.

The second question is answered by analysing both the found variations and what is required from an alert system to be intelligent. It is considered how the variations complicate the development of an intelligent alert system customisable for various vessel types. The situation is compared to one where there would be no variations.

Based on the analysed challenges, a development roadmap for an intelligent vessel alert system for various vessel types is suggested. The proposed order should be such that overcoming the challenges caused by the variations would not initially be too demanding. This means that the vessel types are put in such order that the ones with the smallest variations are suggested to be focused on first and the ones with the biggest last.

The third research question is answered by developing an MS Excel solution that takes the variations into account and therefore helps to do the customisation more optimally. In the implementation of the Excel solution the knowledge gathered in the literature part and the earlier results of this thesis are utilised. The developed solution is also tested with a couple of alert signal lists from different real-life projects and it is adjusted more optimal by analysing the test results.

1.4 Methodology

To get exact and generalizable results of the variations in vessel alerts and alert systems would be a truly demanding task. That would require collecting enormous amount of alert system data, as there are tens of thousands of different vessels in the global fleet. In addition, that data is most often classified, meaning gathering it in the first place is very difficult. Thus, this thesis does not try to reach for that. Instead, the purpose is to build up an overall picture of the differences in the alerts and alert systems.

The two research methods applied in this thesis are interview research and text analytics. As interviews are utilised for gathering information on vessel alert and alert system variations, text analytical methods are applied in the development of the Excel tool which, as an outcome of this thesis, is given as an example solution for the customisation problem.

As mentioned, acquiring alert system data is difficult. Yet, the goal is to study the variations in alerts and alert systems of different maritime vessels. This is why the information was decided to be gathered by interviewing maritime experts. In addition, as Hirsjärvi and Hurme [26, p. 35] describe, there are several situations in which interview is an effective research method – of those the following ones match with the nature of this thesis:

- The subject has a little of previous survey
- The research topic will probably produce a large variety of answers referring to many directions
- It is possible to clarify the answers; this is not possible with e.g. questionnaires
- The received information is wanted to deepen, e.g. by asking additional questions or requesting arguments for the answers

These reasons contributed the decision to utilise interview as a research method in this thesis. In more detail, the chosen form of interview is semi-structured theme interview, in which the question frame and themes are the same in every interview but the wording and order of the questions might vary.

The other of the two utilised research methods is text analytics and in more detail text classification. It is a function that automatically assigns textual data into pre-defined categories based on their content. Some applications utilising it are, for instance, email classification, topic identification and text genre classification. [27, pp. 3041–3043] In this thesis, text classification is applied in the developed Excel solution, which functions as a tool categorising alert signals into pre-defined groups.

In addition to interview research and text classification, grouping methods of the SFI Group System [28] are applied. They are utilised when defining the pre-defined signal groups of the developed Excel solution.

1.5 Structure of the thesis

This thesis contains eight chapters, each of them having various amount of sub-chapters. The literature part of this thesis is divided into chapters 2 and 3. Of them, the first one gives an introduction to the basic vessel structure, functions, machinery systems and equipment as well as to the different types of maritime vessels. After that, chapter 3 presents the most important regulating actors in the maritime industry and also provides basic knowledge of maritime automation and alert systems. In chapter 4, the research methods introduced in the chapter 1.4 are explained in more detail.

The applied part of this thesis consists of chapters 5, 6 and 7. In chapter 5, the executed interview study is gone through. The development of a signal list categoriser, which is implemented by utilising the interview results, is presented in chapter 6. The main results are summarised and discussed in chapter 7. Finally, this thesis is summed up in chapter 8, in which also potential future work is discussed.

The two appendices can be found at the end of this thesis, after the text chapters and references. Appendix A contains the question frame used in the interviews and various screenshots of the developed signal list categoriser Excel workbook are found in Appendix B.

2. MARITIME VESSELS AND MACHINERY SYSTEMS

Before going into maritime vessel automation and alert systems, it is reasonable to shortly discuss ships in general, i.e. what are the main parts, systems and machinery of them and what types of vessels there are in the global merchant fleet. This enables comparing various vessel types and finding differences and similarities between them in the later parts of this thesis.

In the first section of this chapter the structure and systems of a general ship are introduced. After that, in sub-chapter 2.2, the common machinery systems and equipment found on board are gone through. In the last section of this chapter the different maritime vessel types and their main characteristics are described.

2.1 Structure, machinery and systems of a general ship

Modern ships can be considered as complex systems integrating various sub-systems and their components, such as cargo storage and handling, electric power generation, ship propulsion, navigation etc. [29, p. 14]. These sub-systems perform the basic ship and payload functions of a maritime vessel. Basic functions of a general ship are presented in Figure 2.1.

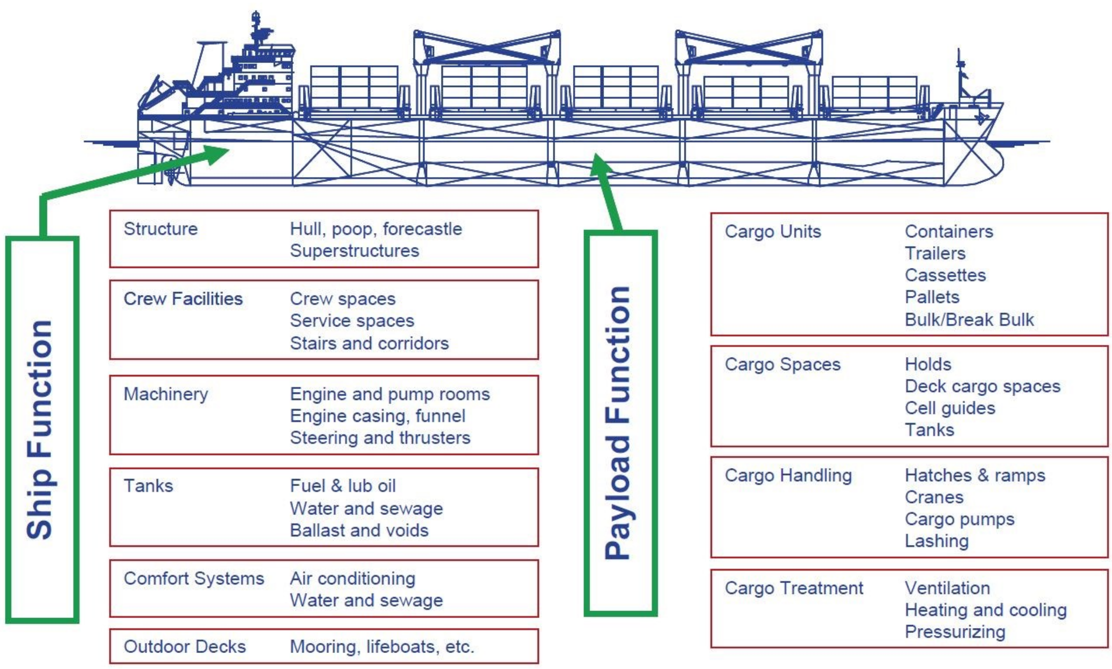

Figure 2.1. *Basic functions of a ship [29, p. 15].*

In the Figure 2.1, basic functions of a ship are divided into ship functions and payload functions, of which the first ones are related to the carriage of payload from port to port, and the second ones to the provision of cargo spaces, cargo handling and cargo treatment equipment [29, p. 15]. These, of course, variate between different vessel types – a ship build for carrying no cargo does naturally not have any payload functions shown in the Figure 2.1 – but in general, a common vessel can be generalised so that it consists of the functions and systems shown in the Figure 2.1. In addition to these, there are generally functions such as fire-fighting and protection systems, instrumentation and control systems, safety systems and also some auxiliary machinery and systems for supporting all the main systems and services on board [30, p. 346].

In this section the basic functions of a ship are considered in the point of view of the machinery systems and equipment related to them. Since machinery alerts form a considerably part of the total vessel alert I/Os, it is reasonable to find out where they originate from.

Häkkinen [31, p. 1] divides ship machinery into five groups:

1. Propulsion machinery
2. Electricity generation machinery
3. Heat generation machinery
4. Auxiliary machinery and systems for propulsion, electrical generation and heat generation
5. Ship auxiliary machinery and systems

The size and operational role of these systems vary depending on the type of vessel. These common machinery systems and equipment are shortly presented in the following to provide a knowledge that can be utilised in the later parts of this work.

Propulsion system

Propulsion system consists of machinery providing thrust for the propulsors, i.e. engines or turbines, and all the shaft lines consisting of drive shafts, bearings, clutches, reduction gears and the propulsion devices themselves [31, p. 1]. Common propulsion devices are such as *fixed pitch propellers, ducted propellers, podded and azimuth propulsors/thrusters, contra-rotating propellers, controllable pitch propellers, waterjet propulsors,* etc. [30, pp. 346–362]. In case of an *electric propulsion system*, the system consists also of the generators and electric motors used by other propulsion machinery as well as all the equipment and cables associated with the propulsion system's electric network [31, p. 2].

On some vessels, the propulsion system is implemented as an *azimuth propulsion system,* which is a combined system for providing propulsion power and steering the vessel. Typical azimuth propulsion system equipment is e.g. podded drives, rudder propellers, rotatable waterjets and cycloid propulsors. [32, p. 489]

Electric power generation system

The function of the electric power generation system of a vessel is vitally important for the vessel's operation and safety, therefore ensuring the electricity supply is crucial. Maritime regulations require that the electricity can be produced with two independent systems of which both, on their own, can supply enough power to maintain vessel's seaworthiness [31, pp. 107–108]. The electricity is usually produced with diesel generators, often called auxiliary gensets, but also with small gas turbines utilising waste heat of exhaust gases [30, pp. 373–374]. The power generation system often consists of three diesel gensets, of which one produces the needed electricity, one is on stand-by and one is for backup. In addition, there is an emergency generator producing electricity for vital consumers in error conditions – on smaller vessels this can be replaced by a battery system. [31, p. 108]

Heat generation system

The heating medium on vessels is normally pressurised steam, other options are hot water and thermal oil. In some limited occasions heating is done with electric heaters. A normal steam heating system of an engine-powered vessel consists of an observation tank, feed water tank and pumps, a waste heat recovery boiler, a boiler and circulation pumps. [31, pp. 122–123] A thermal oil and a hot water heating systems are simpler than a steam heating system as feed water and condensing systems are not needed and the boilers are smaller [31, pp. 135–136].

Auxiliary machinery and systems for propulsion, electric power and heat generation systems

This group consists of machinery and systems that support propulsion, electric power and heat generation systems. Typically these include the following machinery and systems [31, pp. 158–181] [30] [32]:

- **Fuel oil system:** supplies fuel oil (FO) for the engines. FO system can be divided into four sub-systems: unloading, storage, purification and transfer systems. The FO system equipment consists of, e.g., unloading and transfer pumps, tanks, filters and FO separators.

- **Lubrication oil system:** supplies lubrication oil (LO) for engines and other equipment. The LO system can be divided into three sub-systems: unloading and storing, purification and circulating systems. The equipment of an LO system consists of, e.g., unloading and transfer pumps, tanks and LO separators.
- **Cooling water system:** cools down the engines and other equipment. Usually the system is implemented as a central cooling water system consisting of seawater cooling system, low temperature (LT) freshwater circuit and high temperature (HT) freshwater circuit. The HT circuit cools the engine cylinders, the LT circuit the lubrication oil, jacket water and scavenge air from the engines and the seawater cooling system cools down LT and HT circuits with seawater. The normal equipment of the cooling water system comprises water circulation pumps, expansion tanks, heat exchangers, control and mixing valves and deaerating equipment.
- **Charge air system:** supplies the engines with combustion air. Charge air is usually taken from engine room and led through the absorbent filter of turbocharger. Alternatively, the air can be taken from outside. If the air in engine room is extraordinarily dirty, a more effective filter is needed. Also, if the air temperature is below 0 ºC it needs to be pre-heated.
- **Exhaust gas system:** leads the exhaust gases from the engine to the atmosphere. The system includes exhaust gas piping, silencers, exhaust gas cleaning system, e.g. a selective catalytic reduction (SCR) system, and possibly an exhaust gas boiler. Important process values measured in the exhaust gas systems are, e.g., exhaust gas pressure and temperature.
- **Compressed air system:** produces pressurised air for various consumers. The system is divided into starting air, control/instrument air and working air systems, which all have their own consumers. Starting air is produced for starting the main and auxiliary engines, instrument air for the use of pneumatic control equipment and working air for tools and elevators of the vessel. The compressed air system comprises compressors, air bottles, drainage, pressure reducers, relief valves, air dryers and air filters.

Ship auxiliary machinery and systems

Häkkinen [31, p. 189] considers all the machinery and systems not associated with propulsion, electric and heat generation or cargo treatment systems as ship auxiliary machinery and systems. Examples of the most common ship auxiliary machinery and systems are gathered in the following list [31, pp. 189–206] [30] [32]:

- **Bilge system:** a piping system disposing water from vessel's dry compartments in emergency. This water is accumulated due to condensation, leakage, draining, washing, fire-fighting, etc. This *bilge water* is collected in the bilge water tank, treated to reduce oil content and finally released into the environment. The main equipment of bilge system normally consists of bilge water tank and self-priming bilge pumps, oily/water separator, mud boxes and backpressure valves.

- **Fire-fighting and protection:** regarding fire-fighting and protection, vessels are divided into three sections: accommodation, engine room and cargo holds. The requirements for fire-fighting vary between vessel types, depending on the type of cargo and amount of passengers on board. Water extinguishing is mandatory, as it extinguishes fire and cool downs structures. Other methods are gaseous fire suppression, utilising mainly CO_2, and use of water mist and fire foams, which all are useful especially for extinguishing burning liquids and electric devices. Main equipment of a fire-fighting system consists of fire detectors, fire water tank and pumps, sprinklers and portable fire extinguishers. Fire-fighting system is usually equipped with an own alert system.
- **Ballast system:** stabilises the vessel, improves vessel's behaviour on waves, reduces the risk of slamming and improves propeller and rudder functions. Ballasting is crucial on cargo vessels sailing without cargo loads. Main equipment comprises ballast water pumps and tanks and ballast treatment system, which is used for eliminating invasive species before the ballast water is unloaded.
- **Roll stabilisation system:** reduces roll of the vessel caused by waves or wind, which may damage cargo, reduce passenger comfort and crew efficiency and, in some cases, increase resistance and therefore vessel's fuel consumption. Stabilising is normally done, depending on the speed of vessel, with active-fin stabilisers or anti-roll tanks, a combination of them both or alternatively with a movable-weight system. A more sophisticated method is *rudder roll stabilisation* which is an adaptive control system utilising the vessel's steering gear and rudder.
- **Steering system:** a system which moves the rudder stock, i.e. steers the vessel, based on the control signals given on the bridge. The main parts of the system are control equipment, a power unit and a transmission to the rudder stock, i.e. steering gear. Maritime regulations require that a vessel must have two independent means of steering, thus an *auxiliary steering gear* is also found on the vessels.
- **Transverse thrusters:** a propulsion device improving vessel's manoeuvrability, used especially on large ships which suffer more from wind. Transverse thrusters are usually installed at the bow (bow thrusters) and sometimes at the stern (stern thrusters) of the vessel. The thrust is provided with an electric or hydraulic auxiliary drive.
- **Anchoring and mooring system:** a system which anchors the vessel on the seabed and moors it at a pier or elsewhere. The system consists of anchoring and mooring winches, which are either electrically or hydraulically driven.
- **HVAC system:** Heating, Ventilation and Air-Conditioning (HVAC), a system that circulates, changes, heats and cools the air on vessel. It improves the comfort, air quality and fire safety on board.

- **Distillation system:** distils fresh drinking water from sea water. Main equipment consists of an evaporator, a condenser, fresh water tank and pumps.
- **Dynamic positioning (DP) system:** a system controlling or maintaining the position and heading of the vessel by utilising its propulsion system. It functions by responding automatically to the measured variations in environmental conditions and vessel's position. DP system comprises three sub-systems: power system, thruster system and DP control system.

Even though the systems and machinery listed above are considered auxiliary, they have a significant role in the operation of a vessel. Also, in the point of view of vessel alerts, these are systems that generate a lot of them. For instance, according to Tanner [33], 38 % of alert I/Os and 64 % of all occurred alarms of large passenger ships originate from HVAC system.

2.2 Maritime vessel types

Since this thesis aims to build a knowledge about variations in alerts and alert systems of different vessel types, it is relevant to shortly look into the various types of ships in the global merchant fleet. According to Equasis' statistics of the world's merchant fleet, in 2016 there were approximately 90 000 merchant vessels of 100 gross tons and above in the global fleet, with numerous different types of vessels [34, pp. 3–5].

When speaking of ships, they are usually first categorised into certain main groups and then further into more specific vessel types. In the IMO's publication *Safety of Lives at Sea* (SOLAS) [35, ch. 1] it is done by dividing all the vessels into just two main categories, as follows:

- **Passenger ships***:* all ships carrying more than 12 passengers.
- **Cargo ships***:* all other ships other than passenger ships.

Other references do this categorisation in various ways: for instance Equasis uses 12 principle types into which vessels are grouped [34, p. 3] and Molland divides them into four main groups: *merchant ships*, *high speed craft*, *yachts* and *warships* [30, p. 44]. Papanikolaou [29, pp. 35–38] on the other hand introduces several ship categorisation methods and criteria, of which the following gives some examples:

- **Mission profile:** merchant ships, naval and coast guard ships, research/hydrographic vessels, sport boats, tug boats, icebreakers, dredgers, support vessels, pilot boats and cable ships.
- **Operation area:** open/deep water ships and inland ships, i.e. river and lake boats.
- **Main machinery/engine type:** e.g. steam ships, turbine (steam-powered and gas-powered) ships, diesel engine (low-speed, medium-speed, high-speed) ships,

ships with combined diesel and gas turbines, ships with ‘green’ environmentally friendly prime or auxiliary energy sources, etc.

- **Type of transported cargo:** general cargo ships, bulk carriers, tankers, gas carriers, break bulk carriers, multipurpose cargo ships, passenger ships, short sea passenger transport ships, excursion boats.

As mentioned, in the main categories the vessels can be given more specific types. For instance a vessel could be a cargo ship, more specifically a tanker and in detail a chemical carrier. Figure 2.2 provides a collage of the many different maritime vessel types.

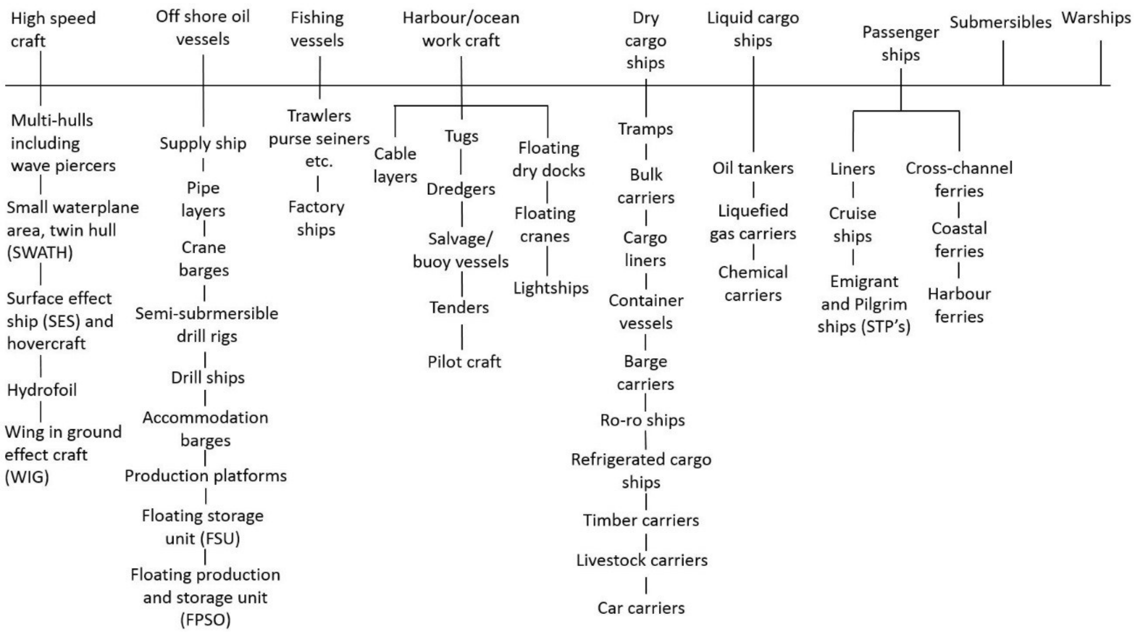

Figure 2.2. *Types of maritime vessels. Adapted from [36, p. 18].*

As can be seen, in the Figure 2.2 ships are divided into nine main categories, in which they are given more detailed sub-groups. As there are many of those detailed ones, not all of them are relevant for this study. Of the main groups of the Figure 2.2, high speed craft, submersibles and warships are left out of the scope of this work and of the other six main categories not every vessel type is further introduced. Consequently, the following sub-chapters provide short descriptions only for the most relevant vessel types for this study. Based on their mission profile, those vessel types are divided into three following main categories: cargo vessels, passenger ships and service vessels.

2.2.1 Cargo vessels

Cargo vessels are ships used for transporting goods. They can be grouped by the type of cargo they carry, commonly into five main types: general cargo ships, container ships, tankers and dry bulk carriers. Other types of cargo ships are Roll-on roll-off (Ro-Ro) vessels and car carriers. [30, pp. 45–46]

Cargo vessels are the most common ships in the world fleet – of the world's 89 804 commercial vessels in 2016 general cargo ships were 16 433 (18.3 %), dry bulk carriers 11 614 (12.9 %), different types of tankers in total 16 121 (18.0 %) and container ships 5 107 (5.7 %) [34, p. 6]. This sums up 49 275 and 54.9 % of all merchant vessels.

Common for cargo vessels is that they are usually build so that they carry up to 12 passengers at maximum to avoid the passenger ship regulations [30, p. 45]. The structure of these vessels is rather simple and due to small amount of passengers, not broad comfort services are needed. In the automation point of view this means that the number of I/Os is significantly smaller than on passenger ships and complex off-shore vessels, for instance.

The following introduces shortly five types of cargo vessels: general cargo and container vessels, tankers, dry bulk carriers and Ro-Ro vessels.

General cargo ships

A general cargo ship is a flexible type of vessel capable of carrying break bulk cargo, liquid cargo and/or containers in many kinds of conditions. They have several large clear open cargo holds with one or more decks known as 'tween decks'. General cargo ships are equipped with cranes and derricks for cargo handling. Generally they are smaller than bulk carriers and their typical speed range is from 12 to 18 *knots*. [30, p. 45]

In case perishable cargoes are carried, general cargo ships are equipped with a refrigeration system and holds are insulated. Since the cargo often decays quickly and keeping it refrigerated is expensive, these *refrigerated cargo ships* or *reefers* are usually faster than general cargo ships with speeds up to 22 *knots* – with higher speeds journeys take less time. [30, p. 45]

Container ships

Vessels carrying exclusively containers are called container ships. Their capacities are expressed in TEU, i.e. twenty-foot equivalent units. In order to make the operation of container ships more profitable, the vessels tend to be very large and with speeds up to 30 *knots* faster than general cargo ships. The sizes have grown rapidly in the past decades and it seems they keep on growing also in the future. [30, p. 49] [27, pp. 136–138]

Tankers

Tankers are vessels transporting liquids, main types of them being *crude oil, product, liquefied gas* and *chemical tankers* [30, pp. 52–55]. Tankers are of various sizes and capacities as the smallest of them with capacity of several hundred tons serve small harbours and coastal settlements and the biggest do long-range haulage with several hundred thousand tons of liquid [37]. The following introduces them shortly.

- **Crude oil tankers:** tankers carrying unrefined crude oil. Sizes vary depending on the route they sail. Panamax tankers have a preferred size between 35 000–45 000 *dwt*, Aframax tankers between 70 000–120 000 *dwt* and Suzemax tankers between 120 000–165 000 *dwt*. Additionally, Very Large Crude Carriers (VLCCs) have a size of 200 000–310 000 *dwt* and Ultra Large Crude Carriers (ULCCs) of 310 000–550 000 *dwt*. [27, p. 438]
- **Product tankers:** tankers carrying refined oil products, e.g. gas oil, aviation fuel and kerosene. Sizes vary between 18 000–75 000 *dwt* and speeds between 12–18 *knots*. [30, p. 53] The main difference between a product tanker and a crude oil tanker is that the product tanker is smaller and it carries several types of cargo simultaneously. Due to this, product tankers have several cargo tanks and complicated pumping and piping systems for handling each type of cargo separately. [27, p. 602]
- **Liquefied gas carriers:** tankers carrying liquefied gases, i.e. liquefied natural gas (LNG) and petroleum gas (LPG). LNG carriers have sizes up to 140 000 m^3 and LPG carriers up to 95 000 m^3, their speeds range from 16 to 19 *knots*. To keep the gas liquefied requires right temperature and pressure levels – LNG is normally stored at atmospheric pressure and −164 °C and LPG at low temperature and/or high pressure, e.g. at −7 °C and 7 bar or at −45 °C and atmospheric pressure. This sets high demands for vessel structures, insulation and systems. [30, pp. 53–55]
- **Chemical carriers:** tankers designed for carrying liquid chemicals in bulk. The IMO defines three types of chemical carriers according to the dangerousness of the cargo: ST1 for the most dangerous, ST2 for significantly dangerous and ST3 for moderately dangerous chemicals. Before a vessel can be classified as a chemical tanker, it has to satisfy strict requirements set by the IMO. These requirements say, e.g., how different types of cargoes should be situated, separated and treated to ensure safety. For instance, many cargoes are required to be stored at inter atmosphere which complicates the structure and machinery of the vessel as a nitrogen generating plant has to be fitted on board. [27, pp. 107–110] The common sizes of chemical carriers range from about 5 000 *dwt* to 50 000 *dwt* [29, p. 484].

Common for all tankers is the risks their cargo cause. For instance chemical carriers carry often toxic and flammable cargo, which put both human lives and the environment in danger. Thus, tankers have to fulfil strict safety requirements, which is demanding for their safety systems.

Dry bulk carriers

Dry bulk carriers are vessels carrying cargoes such as grain, coal, iron ore, phosphate and nitrate. Vessels carrying cargo combinations, e.g. ore and oil, are called *combination bulk carriers*. Typical for dry bulk carriers is that they don't normally have own cargo handling equipment, except for the combination bulk carriers which have equipment for oil handling. The sizes range from 20 000 *dwt* up to 200 000 *dwt*, a typical dry bulk carrier being approximately 150 000–160 000 *dwt* and 280 m long. [30, pp. 55–58] [29, p. 70]

Ro-Ro cargo vessels

Ro-Ro cargo vessels are designed for carrying wheeled cargo, mainly vehicles but also roll trailers and cassettes. As there were, according to Equasis [34, p. 6], 1487 Ro-Ro cargo vessels in global fleet (1.7 % of all merchant vessels) in 2016, Ro-Ro cargo vessels are not even close as common as the four main types of cargo vessels.

Ro-Ro vessels have usually one or more large open or closed decks and the cargo is rolled on board at one end of the vessel and rolled off at the other. Commonly they are equipped with bow and high lift rudders to ensure good manoeuvrability also at low speeds. [32, pp. 519–520] Ro-Ro vessels often operate on short routes with relatively high speeds of 18–22 *knots*. Their sizes vary significantly about 16 000 *dwt* being rather common. [30, p. 51]

2.2.2 Passenger ships

Passenger ships are vessels used for carrying more than 12 passengers. As it is seen in the Figure 2.2, different types of passenger ships include *ocean liners, cruise ships* and various sorts of *ferries*, such as *coastal ferries* and *cross-channel ferries*. Nowadays passenger ships are mostly either cruise ships or ferries, as ocean liners are forced aside by aeroplanes.

Common for all passenger ships is that they are the vessels that are affected the most by changes in standards. In order to ensure safety of human lives the safety regulations are strict. Also, they are equipped with comprehensive accommodation and leisure facilities, which makes them more complex systems than some simpler vessel types, e.g. cargo vessels. [30, p. 58]

The following gives short introduction to the cruise ships and ferries and to their technical features.

Cruise ships

Cruise ships are huge vessels transporting people mainly for leisure voyages. Perhaps the most famous ones of them are the Caribbean cruise ships, which hold the biggest market. The biggest cruise ships have length more than 300 metres, height more than 60 metres, width up to 60 metres and they are capable of carrying thousands of passengers at 22 *knots*. [30, p. 58] For instance, as of October 2018 the world's largest cruise ship, *Symphony of the seas*, has a width of 66.7 m, length of 362 m and carries up to 6680 passengers and 2200 crew members with a speed of 22 *knots* [38].

Cruise ships are designed to provide passengers services of a high standard. These include e.g. accommodation and leisure facilities, large open lounges, swimming pools, etc. This makes them very big systems and yet at the same time they have to be well stabilized and have good manoeuvrability which puts high requirements for the machinery and auxiliary systems. On the whole this makes them technically one of the most complex vessels. [30, p. 58]

Ferries

Ferries are vessels transporting passengers, vehicles and some cargo across a body of a water. Technical characteristics of ferries are determined to a great extent by the amount and type of passengers they carry and the route they sail. They could be grouped into simpler and smaller (common) *ferries* and *cruise ferries* which are bigger and more complex. As common ferries are vessels carrying only deck passengers and having limited leisure services, cruise ferries have also cabin spaces and comprehensive leisure services, such as restaurants, bars and lounges for the passengers, and they operate overnight routes. [32, p. 235]

Technically ferries are often a combination of a Ro-Ro vessel and a passenger ship, i.e. a so-called RoPax vessel. They are loaded with vehicles from one end and unloaded from the other, usually equipped with bow thrusters and stabilisers to improve seakeeping and manoeuvrability and commonly sail at speed of 20–22 *knots*. [30, pp. 58–60]

2.2.3 Service vessels

Vessels that are used for other functions than transporting something, i.e. passengers and/or cargo, can be categorised into group of service vessels – as their primary function is to do some sort of service, e.g. fishing, towing, cable laying, ice breaking, etc.

The following introduces briefly the types of service vessels that are considered the most relevant for the scope of this thesis. These are tugs, icebreakers and off-shore service vessels.

Tugs

Tugs are service vessels performing numbers of different tasks, such as towing vessels, helping large ships manoeuvre in confined waters, fire-fighting and moving dumb barges. Common features for a tug are an efficient design, a high thrust and an ability to get close alongside other vessels as well as a good manoeuvrability and stability. Modern tugs are equipped with azimuth propulsion systems, are of 30–45 m long (biggest ones up to 45 m) and have power of 2500–5000 kW. [30, pp. 60] According to Equasis [34, p. 6], tug is also the most common type of vessel, as there were 18 199 tugs in 2016, making 20.3 % of all commercial vessels.

Icebreakers

Icebreakers are vessels used for making passages at sea, in rivers and in ports usable for other ships during winter by clearing the ice. Due to their mission profile and the demanding environment they sail in, icebreakers are expensive to build and operate. For instance, they have to be strengthened with steels, have extra structures in the bow and along the waterline, have high power propulsion and manoeuvring devices and they need to be capable of riding up over the ice. [30, pp. 60–62]

Off-shore service vessels

Off-shore service vessels (OSVs) are vessels carrying out supporting tasks for floating drilling rigs and moored production platforms of off-shore oil and gas industry. OSVs are categorised according to their tasks and the wide range include e.g. seismic survey vessels, platform supply vessels, anchor handling tug and supply vessels, off-shore construction vessels and various multipurpose vessels. Common for OSVs is that a lot is required from their machinery and systems as they, e.g., operate in bad weather conditions, are equipped with diverse equipment and have to have particularly good position keeping capability and high power. [32, pp. 426–432]

3. MARITIME STANDARDS AND AUTOMATION & ALERT SYSTEMS

After discussing maritime vessels and their machinery in the chapter 2, it is practical to move on to the maritime automation and alert systems. Also, as the maritime industry is rather regulated for ensuring safe and clean operations in the seas, it is reasonable to shortly discuss the various rules affecting these automation and alert systems.

In the first section of this chapter the maritime standards and regulations and the main regulating actors, i.e. the IMO and classification societies, are introduced. In sub-chapter 3.2 a general knowledge of modern maritime automation system is given and in section 3.3 maritime alert systems are discussed.

3.1 Maritime standards and regulations

Maritime technology is covered with many standards, recommendations and regulations that aim to increase and ensure safe and environmentally friendly operations at sea. Due to the international character of the maritime operations, these regulations are mainly based on international agreements [39].

The most important organizations regulating ship building are the International Maritime Organization (IMO) and various classification societies. In addition, standardization organizations, mainly International Electrotechnical Commission and International Organization for Standardization, have a role in the maritime regulations and therefore in alert system requirements.

For vessel alert systems especially safety requirements are important. Due to this, it is meaningful to introduce the most important regulating actors and their alert system and safety regulations in this work.

3.1.1 International Maritime Organization

The slogan of the International Maritime Organization sums up the IMO's objectives: *safe, secure and efficient shipping in clean oceans* [40]. In other words the objectives could be described as an aim to improve the safety of the maritime operations and to avoid misunderstandings due to cultural and linguistic differences by enabling unified international maritime practices. In addition, the IMO aims to harmonize the contents and the outfit and to decrease the amount of the documents concerning international maritime operations. [39]

The United Nations (UN) established the IMO in 1948 to improve safety in maritime operations after it had long been seen that safety regulations given in national levels were inefficient in international shipping industry. Since then the IMO has grown into an organization of 170 member nations and become definitely the most important internationally operating actor regulating ship building. Nowadays it operates with its own and independent budget under the UN's Economic and Social Council and its importance in modern and globalized world is significant. Instead of giving only advices, the IMO also gives orders which concern all of its member states. [39][40]

The IMO gives its orders and recommendations by publishing public documents. These documents are either formal treaty instruments, like international Conventions, or recommendations, like constitute Codes, recommended practises or guidelines. [40] As international Conventions are general agreements concerning everybody in the shipping industry, Codes usually concern only certain vessel and cargo types [39]. Some of the codes, however, have been made mandatory under the relevant provisions of SOLAS and/or MARPOL (*the International Convention for the Prevention of Pollution from Ships*), which are perhaps the most important IMO Conventions. [40] Regarding this thesis, the most relevant IMO documents, SOLAS, *Code on Alerts and Indicators* and *Adoption of Performance Standards for Bridge Alert Management* are shortly introduced in the following paragraphs.

Safety of Life at Sea (SOLAS)

The *Safety on Life at Sea* (SOLAS) is an IMO convention which aims to specify minimum standards for the construction, equipment and operation of ships [30, pp. 795]. Its first version was adopted in 1914 and the fifth and latest version came in 1974. Since then it has been updated and amended several times into a version including articles setting out general obligations, amended procedures, etc., followed by an Annex divided into 14 chapters. [41] Of those 14 Annex chapters, especially Chapter II-I is the one regulating alert systems and thus important for this thesis.

Chapter II-1 – Construction – Subdivision and Stability, Machinery and Electrical Installations includes requirements covering machinery and electrical installations aiming to ensure services that are essential for the safety of the ship and that passengers and crew are maintained under various emergency conditions [41]. It contains some regulations that set requirements also for alert systems. Those can be, for instance, certain required alerts, such as an alarm that shall be given when a watertight door is opened or closed, when certain important equipment fails or when hydraulic oil level in a tank is low indicating a leakage. In addition, there are some general regulations for alarm system itself and how it should be built, e.g. for electric power and fault protection of the alarm circuits. Of the chapter's many regulations, however, *Regulation 51 – Alarm system* is perhaps the most important one giving requirements for vessel alert systems. It is meant for vessels with periodically unattended machinery spaces and does not thus concern all vessel types.

However, to give an overview of the relevant rules and requirements of SOLAS, some of the alert system requirements from the Regulation 51 are summarised in the Table 3.1 below.

Table 3.1. *Summarisation of Regulation 51 - Alarm systems of SOLAS [35].*

No.	Description
1.	An alarm system shall indicate any fault requiring attention and: 1. be capable of sounding an audible alarm in the main machinery control room or at the propulsion machinery control position, and indicate visually each separate alarm function at a suitable position; 2. have a connection to the engineers' public rooms and cabins; 3. activate an audible and visual alarm on the navigation bridge for any situation which requires action by or attention of the officer on watch; 4. as far as is practicable be designed on the safe-to-fail principle; and 5. activate the engineers' alarm if an alarm function has not received attention locally within a limited time
2.1.	The alarm system shall be continuously powered and have an automatic stand-by power supply.
2.2.	If the alarm system's normal power supply fails, it shall be indicated by an alarm.
3.1.	The alarm system shall be able to indicate simultaneously more than one fault and the acceptance of any alarm shall not inhibit another alarm.
3.2.	Acceptance of any alarm condition shall be indicated at the positions where it was shown. Alarms shall be maintained until they are accepted and the visual indications of individual alarms shall remain until the fault has been corrected, when the alarm system shall automatically reset to the normal operating condition.

As it is seen in the Table 3.1, SOLAS does not regulate alert systems in detail but more in a general way. It is told what should be done but not how it would be achieved. For instance, the alarm system is required to be equipped with an automatic stand-by power source, which is free to be e.g. a battery or a stand-by generator, as long as it ensures a continuous power supply.

Code on Alerts and Indicators

Regarding vessel alerts, the IMO has adopted the resolution A.1021(26), the *Code on Alerts and Indicators* (CAI), whose purpose is to provide general design guidance and to promote uniformity of type, location and priority for the alerts and indicators required by SOLAS. It is not a forceful directive, but the Maritime Safety Committee recommends governments to implement and use it as an international safety standard for designing alarms and indicators for ships and ships' equipment and machinery. [42] In this thesis' point of view, the CAI is naturally the most interesting and relevant IMO document and its relevant parts are utilised in the later sections of this work. Here it is not gone through in detail but only shortly introduced.

The CAI defines alert priorities and criteria how alerts are to be classified into them. It also gives definitions for alert terminology. In addition, it provides guidance on alert system design: e.g. how alerts should be indicated both visually and audibly, how they should be made distinguishable from each other, how they should be acknowledged, how systems should be powered and backed-up, and so on. Furthermore, it contains compilations of required audible and visual signals and symbols for the emergency alarms, alarms and calls, gives detailed requirements for particular alarms, such as personnel alarm, Bridge Navigational Watch Alarms Systems (BNWAS) and Engineers' alarm. In its last section the CAI provides a compilation of alerts required by different IMO instruments and gives them priority and display requirements, i.e. whether they should be emergency alarms, alarms, warnings, cautions or indications and be either audibly, visually or by both ways displayed or be just visual or measuring indicators. [42]

Adoption of Performance Standards for Bridge Alert Management

In addition to SOLAS and Code on Alerts and Indicators, the IMO's Maritime Safety Committee's (MSC) resolution MSC.302(87), *Adoption of Performance Standards for Bridge Alert Management* (BAM), is one of the IMO publications that outlines how an alert system is to be built. BAM contains four following modules giving general requirements and guidelines considering the area of their title [43]:

- Module A – Presentation and handling of alerts on the bridge
- Module B – Central alert management functionality
- Module C – Interfacing
- Module D – System and equipment documentation

Like Code on Alerts and Indicators, BAM is not a forceful directive, but a recommending publication. It is also relatively new and the recommendations are meant for vessels built after July 2014, meaning that it is currently affecting, if applied, only limited amount of vessels. [43] However, it is a good example pointing out that the IMO is giving some effort in standardising and rationalising alert systems.

3.1.2 Classification societies

A classification society is an organization with a very same kind of core purpose as the IMO: to make maritime operations safer and cleaner through technical support, compliance verification and research and development, and most importantly by providing classification and statutory services [44]. There are a broad range of classification societies, which are usually internationally operating, independent companies carrying out inspections to vessels. Since many nations have authorized CSs to do inspections on behalf of them in order to efficiently fulfil the requirements set in the international conventions, CSs have an important role in the maritime industry and ship building. [39]

Classification societies classify vessels, i.e. they give a certificate of classification for a vessel designed and built to the appropriate Rules of a Society. The aim is to verify the structural strength and integrity of essential parts of the ships' hull and its appendages, the reliability and function of the propulsion and steering systems, power generation and all the auxiliary systems maintaining essential services on board. In order to achieve their objective, CSs develop and apply their own rules and verify compliance with both national and international statutory regulations, e.g. regulations of the SOLAS convention. [44]

When a vessel meets the rules of a relevant CS it is given a certificate of classification and it is said to be 'in class'. This certificate of classification, however, is not and should not be taken as a guarantee for ship's safety, seaworthiness or ability to execute its tasks. Due to CSs inability to control how vessels are manned, operated and maintained, the classification certificate is only a validation that the ship meets the Rules of the CS issuing the certificate [44].

Even though there are several different CSs their rules are nowadays well standardized. This is enabled by an umbrella organization, the International Association of Classification Societies (IACS), which was formed after the IMO's Convention for the International Load Lines required different CSs to tighten their co-operation. The IACS's role is to act as an official representor of its member CSs and to form a collaboration between them. [39]

The standardised classification rules, the Unified Rules, is one product of the IACS's work. They can be found for instance in the IACS's publications 'The IACS Green Book' and 'The IACS Blue Book', of which the first one is updated every time a new or revised IACS resolution or recommendation is uploaded on the IACS website and the latter one once a year [45]. The rules are on many parts based on the regulations given in SOLAS. For instance the *Regulation 51 – Alarm systems* of SOLAS is interpreted into classification rules in the requirement *'M29 – Alarm systems for vessel with periodically unattended machinery spaces'* whose some requirements are shown as an example in Table 3.3.

Table 3.2. *Examples from the Requirement M29 of the IACS's Unified Rules [46].*

Number	Description
M29.2.3	The system is to be so designed that the engineering personnel on duty are made aware that a machinery fault has occurred.
M29.2.6	The alarm system should be designed with self-monitoring properties. In so far as practicable, any fault in the alarm system should cause it to fail to the alarm condition.
M29.2.7	The alarm system should be capable of being tested during normal machinery operation. Where practicable means are to be provided at convenient and accessible positions, to permit the sensors to be tested without affecting the operation of the machinery.
M29.2.8	Upon a failure of normal power supply, the alarm system is to be powered by an independent standby power supply, e.g. battery. Failure of either power supply to the alarm system is to be indicated as a separate alarm fault. Where an alarm system could be adversely affected by an interruption in power supply, change-over to the standby power supply is to be achieved without a break.

The Table 3.3 shows four of the 11 regulations given in the Requirement M29 of the IACS's Unified Rules. Of those four, M29.2.7 is an own developed rule of the IACS and the rest are adapted from the Regulation 51 of SOLAS. When comparing the SOLAS regulations and the IACS's rules, one can see that the IACS's rules a bit more practical, as they give some examples of how the requirements could be fulfilled. However, neither of them dig deep into details and mainly generally tell how systems should be build and what kind of features they are to have. In the alert system point of view these rules and regulation guarantee a little similarity between systems.

3.2 Maritime automation systems

A vessel automation system's purpose is to help the crew to operate the systems on board more easily and safely by executing actions too complicated for the crew to handle in a given time. It also enables automatic observation of systems, registration of failures, registration of service time and planned maintenance. [47, p. 139] In maritime industry, automation systems are either integrated or stand-alone systems, the first one being more common in the modern vessels with their complex functionalities [48, p. 10]. Therefore, Integrated Automation System (IAS) and Integrated Control and Monitor System (ICMS) are normally the terms used when referring to a maritime automation system.

The automation system being integrated means that many kinds of different functionalities and applications are built-in to the system. Some of these applications differ between different vessel types and depending on the level of automation. As an example, the applications included in a typical delivery of Kongsberg's *K-Chief 600* for a tanker are presented in the Figure 3.1.

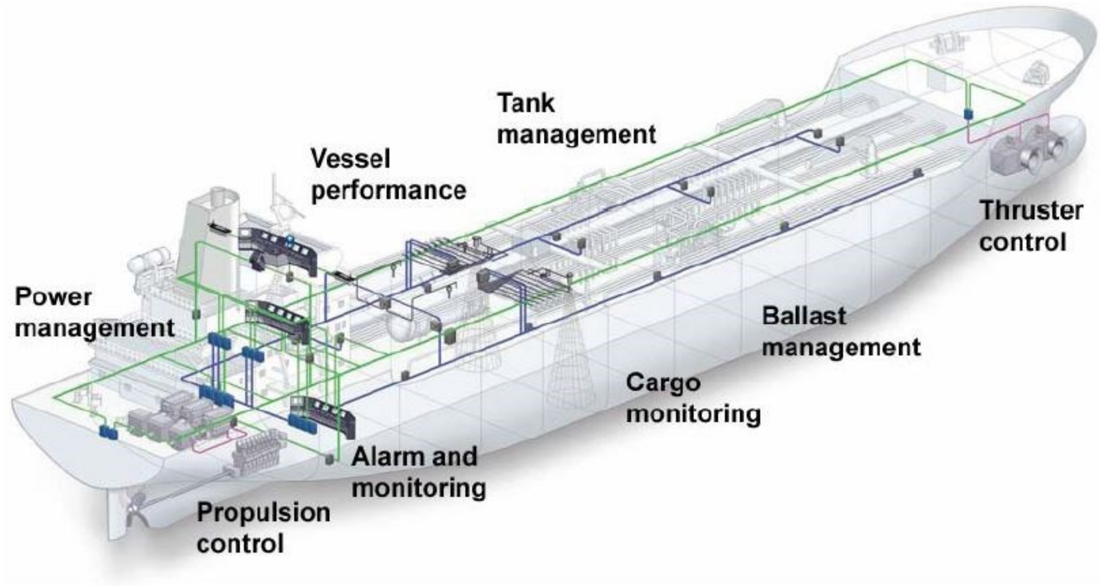

Figure 3.1. *Typical delivery of Kongsberg K-Chief 600 for a tanker [37].*

Even though illustrating a tanker, the applications shown in the Figure 3.1 are mostly such that they can be found on most of the modern ships as they ensure proper operations of the ship. The applications in the Figure 3.1 are also the ones provided by Kongsberg's K-Chief 600, but they can be considered universal in modern systems as they can also be found in other system suppliers' products. Other vessel automation system products are for instance ABB's Ability, Valmet's DNA and Evolution V5 by Rockson Automation, Wärtsilä's NACOS and Acon by Rolls-Royce. The typical applications of an IAS are summarised in the Table 3.4.

Table 3.3. *Typical applications of Integrated Automation Systems [37][49].*

Application	Description and main tasks
Power management	Controls the power generation and distribution on-board, ensures electrical power availability
Propulsion control	Monitors and controls the propulsion power availability
Alarm and monitoring	Gives ship's officers all the basic alarm and status information to maintain safe and efficient operation of the machinery and other related equipment
Vessel performance	Provides the operator with information, such as fuel consumption, engine power output and emissions as well as methods for energy management, e.g. fuel savings and emission reduction
Cargo monitoring	Enables monitoring of measurements, such as level, pressure and temperature, from cargo holds and tanks
Tank management	Enables monitoring of tank measurements, such as level, pressure and temperature, from e.g. cargo, ballast and service tanks
Ballast management	Provides remote monitoring and operation of ballast tanks, pumps and valves from the bridge, engine control room or cargo control room
Thruster control	Provides manual remote control of main propulsion, thrusters and steering gears

In addition to the ones shown in the Table 3.4, IASs provide applications like Condition Monitoring Systems for engine protection, video surveillance and recording, decision support for the operators and vessel data access systems for continuous and remote access to primary vessel data on board and at shore [37][49]. Before emerge of the modern IASs, these functions were covered by vessel systems' own control applications. For instance, there were separate stand-alone ballast management, power management and cargo monitoring and control systems on board. These are still found on simpler and older vessels, and as the average age of a commercial vessels is 19 years in developed countries and 29 in others, there are thousands of those kind of vessels in the world commercial fleet [50, p. 27].

3.3 Maritime vessel alerts and alert systems

The CAI defines an alert as follows: *'Alerts announce abnormal situations and conditions requiring attention. Alerts are divided in four priorities: emergency alarms, alarms, warnings and cautions.'* [42] This differs from other industries where *alert* often refers to a notification less crucial than an alarm. For instance ANSI/ISA-18.2 defines an alert as *'an audible and/or visible means of indicating to the operator an equipment of process condition that requires awareness, that is indicated separately from alarm indications, and which does not meet the criteria for an alarm'* [51, p. 16]. EEMUA 191 gives a somewhat similar definition by stating that an alert is *'a lower priority notification than an alarm that has no serious consequence if ignored or missed'* [52, pp. 55–57].

Alerts are indicated by vessel alert systems, which are used for automatically monitoring the condition of the vessel. Their primary function can be adapted from EEMUA 191: *to direct the crew's attention towards operational conditions requiring timely assessment or action.* This is achieved by annunciating signals, i.e. alerts, which typically consist of an audible sound, a flashing indication, an alert tag and a descriptive alert message. Alerts are generally caused by a process measurement that has passed a set alarm limit indicating that the vessel operations are unsafe or it is not working efficiently. Other causes for alerts on board can be e.g. fire and flooding. [52, p. 1]

A principle in alert system design is that the operated process is divided into different conditions, for instance into target, normal, upset and shutdown. In these conditions, the measured process value is given a range in which it can vary. If the measurement moves out of a range, the process transits into another condition. These transitions can be used as points for indications and warnings and with important process values for alarms. This provides the crew an opportunity to do precautionary actions to keep the vessel operating in a desirable condition. [51, pp. 28–29]

A basic structure of an alert monitoring and control system is presented in Figure 3.2.

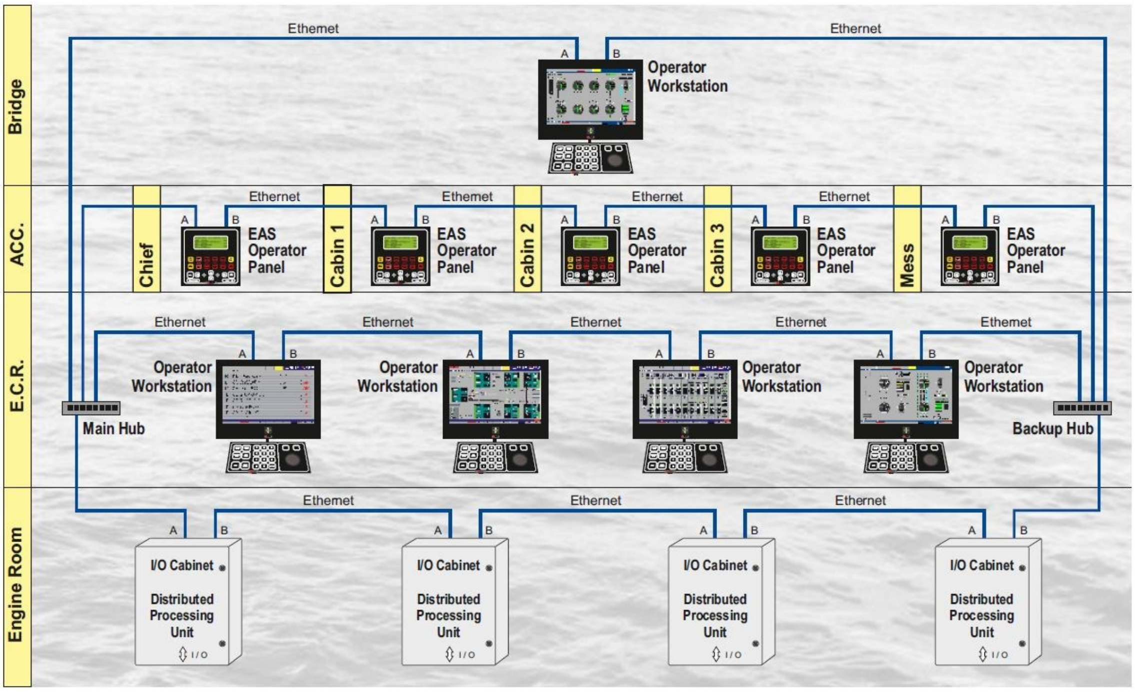

Figure 3.2. *Structure of an alert monitoring and control system [53].*

As shown in the Figure 3.2, function of an alert system can be described by dividing the system in different sections. In the Figure 3.2 those sections are engine room, engine control room, accommodation and bridge. The input signals, i.e. alerts in the case of an alert system, from the vessel machinery and equipment are connected to the I/O cabinets fitted in the engine room. The I/O cabinets distribute alert signals via redundant Ethernet network to the main hubs which send the alert signals further to the operator workstations in the engine control room, to the extension alarm system (EAS) operator panels in accommodation spaces and to the operator workstation on the bridge. When an operator acknowledges an alert on a workstation either in the engine control room or on the bridge, an output signal is send to the corresponding I/O cabinet and the status of the equipment or system returns to normal.

The Figure 3.2 presents a case where the alert system is an independent system even though alert monitoring and control systems are nowadays normally included in IASs. However, the Figure 3.2 might well illustrate function of an alert system integrated in an IAS as the basic principle is the same.

3.3.1 Alarm management and intelligent alert systems

As the number of I/O signals in modern automation systems can be enormous, managing alerts has become problematic. Therefore, mainly in the process industry, research and development has been done to find solutions for this problem. This work has resulted in various white papers concerning methods for alarm management and in some design guidelines and standards giving instructions how an alert system should be engineered.

As described in the section 1.1, in this thesis an alert system implemented to reach the targets of those design guidelines, and thus having sophisticated, state of the art alarm management functions, is considered as an ‘intelligent alert system’.

The key factor enhancing alarm management of an alert system is to reduce the number of alerts indicated to the operator [54]. This can be achieved by, e.g., deleting useless alarms or adding sophisticated alarm management functions to the alert system. Some of these functions are described in the following [52]:

- **Alarm filtering:** predictable secondary alerts are removed. For instance, a failure in a water pump leads to an alert indicating pump failure and probably later to alerts indicating low pressure and flow, which might be less important than the pump failure alert. By filtering the secondary alerts, the operator’s attention can be pointed to more important direction.
- **Alarm grouping:** alerts are grouped so that one alert from a certain group can display various initiating events from a system. This way other alerts from the same group are not needed to display for the operator.
- **Alarm prioritisation:** alerts are prioritised according to their level of importance and criticality. Alerts with higher priority are preferred over lower priority alerts, which eases the operator’s work.
- **Alarm rationalisation:** priority and alert settings are determined for a control parameter. This helps, for instance, to delete useless alerts from the system.
- **Alarm shelving:** a function with which the operator can temporarily prevent a nuisance alert from being displayed. Automated shelving, i.e. *auto-shelving*, is useful when applied for repeating nuisance alerts.
- **Alarm suppression:** a logical criteria is used for suppressing an alert that should not have occurred even if the process measurement had exceeded an alarm limit. This is beneficial, e.g., if alerts are indicated from systems that are out of service.

To design such alarm management functions as described above for an existing vessel, the existing alerts need to be analysed and categorised. For instance, to build an alarm filtering, grouping and suppression features requires categorising the alerts based on their origin and designing an alarm prioritising and shelving functions evaluating their criticality for the vessel operation.

The maritime industry lacks of these kinds of comprehensive guidelines and standards. The two IMO documents presented in the section 3.1, the CAI and BAM, give some sort of guidelines for alert handling, the most practical being the following priorities for vessel alerts [42]:

1. *Emergency alarm.* Alarm indicating that immediate danger to human life or to the ship and its machinery exists and that immediate action should be taken.

2. *Alarm.* Alarm is a high priority of an alert, indicating condition requiring immediate attention and action, to maintain safe navigation and operation of the ship.
3. *Warning.* Indicating condition requiring no immediate attention or action. Presented for precautionary reasons to bring awareness of changed conditions which are not immediately hazardous, but may become so if no action is taken.
4. *Caution.* Bringing awareness of a condition which does not warrant an alarm or warning condition, but still requires attention out of the ordinary consideration of the situation or of given information.

In addition to the priorities, the CAI classifies what kind of alerts should be grouped into certain priorities. For instance alerts like *general emergency alarm* and *fire alarm* have the priority of emergency alarm and alerts like *machinery alarm, control system fault alarm, fire detection alarm* and *gas detection alarm* are alerts with alarm priority. Naturally alerts with alarm priority are significantly more common than emergency alarms, and the CAI does not even specify alerts with warning or caution priority. [42]

Even though the standards set and recommendations given in the maritime industry will not be sufficient for developing an intelligent alert system, they could be utilised to get started. However, guidelines of the other industrial areas should be applied in the development.

3.3.2 I/O signal lists

An I/O signal list of an automation system is a list, most usually an Excel spreadsheet, containing all the automation signals and the data attached to them from independent systems that are wanted to be connected to the main automation system [55, p. 18]. In maritime vessels the main automation system is nowadays most often an IAS and the independent systems are such as propulsion system, main engines, HVAC system, etc., which might have own stand-alone control systems. Connecting the independent systems and sub-systems to the IAS enables controlling them also remotely and manually from the IAS or automatically by the IAS itself. The amount of I/O signals vary according to the vessel type and the level of automation but in general an I/O signal list contains thousands of signals of which a significant part can be alarms.

The signal list is formed by an automation engineer and utilised by the automation system manufacturer when the automation system is programmed and implemented. The signals contain various information, such as an equipment tag or ID, equipment name/description, alarm limits and so on. An example of some alert signals of an I/O signal list is given in Figure 3.3.

ID	Description	Condition Action	Range Low	Range High	Unit	Signal Type	Sensor Type	Alarm Low	Alarm High	Alarm High-high	Delay	Normal Value
404_1_016_XA	Bow Thr. 1 Motor DE-Bearing Temp	ALARM	0	100	°C	AI	Modbus		85	90	5	
404_1_008_XA	Bow Thr. 1 Cooling FW Temp	ALARM	0	80	°C	AI	Modbus		45		2	
404_1_009_XA	Bow Thr. 1 Cooling FW Pressure	ALARM	0	6	bar	AI	Modbus	0.8			2	
404_116_SI	Bow Thr. 1 RPM Feedback	MONITOR	0	100	%	AI	Ethernet	-2			2	
404_117_XI	Bow Thr. 1 Pitch Feedback	MONITOR	-100	100	%	AI	Ethernet	-200			2	
404_105_PAL	Bow Thr. 1 Start Block Motor PS53	LOW PRESS.	1	10	bar	DI	Ethernet	3			10-15	1

Figure 3.3. *Signal examples of an I/O signal list.*

The Figure 3.3 presents 6 automation and alarm signals originating from 'bow thruster 1' of a vessel. All relevant data included in these signals is presented in the figure, those being: Alert ID for identifying the signal, description for clarifying the meaning of the signal, measurement range and unit as well as signal and sensor types. In addition to these, there are condition action, which tells whether the signal is an alarm or indicator ('MONITOR' in the Figure), alarm limits, normal value and delay, i.e. the time after which the alert is given when the alarm limit has been exceed.

If the design principles of an alert system are considered for, e.g., the drive end bearing of the bow thruster motor, i.e. the first signal in the Figure 3.3, a normal condition would be under the temperature of 85 °C and an upset condition between 85 °C and 90 °C. Now, applying these condition limits and the alert priorities provided by the CAI would mean that a warning is given when the temperature exceeds 85 °C and an alarm when it goes over 90 °C. If the equipment was crucial for the vessel operation and safety, there might also be limits for target and shutdown conditions and thus for a caution and an emergency alarm. These could be, for instance, under 80 °C for target and over 100 °C for upset, meaning that exceeding 80 °C would trigger a caution and 100 °C an emergency alarm.

4. METHODOLOGY

A significant challenge in comparing alerts and alert systems of various vessels and finding differences between them is that there are tens of thousands of merchant vessels in the global fleet. This means that doing an objective analysis of the variations would require enormous amount of data – even if the scope was limited into certain vessel types of certain age, for instance. Thus, in this thesis a statistical analysis did not come into question and a different kind of approach was needed.

This chapter introduces the methods utilised in this work. The first section introduces interview research which is used in this thesis for knowledge acquisition. This is followed by the introduction of text analytics and text classification methods which are applied in developing an alert signal list categoriser tool in MS Excel. Also, the SFI Group System and its grouping methods which are utilised in the development of the signal list categoriser are shortly introduced.

4.1 Semi-structured theme interview research

Interview research was chosen for the main data collecting method of this thesis. This was due to the complexity of the starting point of this study; there are numerous different vessel categories, in which there are many different vessel types, and also the vessels are usually seen as individuals, different from any other. In addition, there are various commercial vessel automation and alert systems that differ from each other. By interviewing experienced people that have operated different kinds of maritime vessels it is possible to get a comprehensive view of how things practically work on board, and in this case how the alerts and alerts systems differ between various vessels and vessel types in the operational point of view.

There are a broad range of differently named interview research methods but mostly they differ between each other in the level of structuration, i.e. how strictly the interview questions are formed and how much the interviewer structures the interview. Basically, the different interview research methods can be grouped into following three main types:

- **Structured interview**: an interview in which all the questions are asked exactly in the same way and order from every interviewee. This is the most popular type of interview and it is at its best in cases where, for instance: a formal hypothesis is wanted to be tested, research data is wanted to be quantified quickly and the universality of qualitative results of previous researches is tested.
- **Un-structured interview**: an interview in which the interviewer uses open questions in order to deepen the interviewee's answers. The interviews are much like

conversations in which an answer leads to a new question and so on. This method has traditionally been used by priests and medical doctors but nowadays also by psychologists and sociologists.

- **Semi-structured interview**: an intermediate version of structured and un-structured interview. Questions are same for all interviewees but they can be asked in different order and the interviewees can answer with their own words. [26, pp. 43–48]

Of these three methods the semi-structure interview was the most natural choice. Structured interview would not be applicable since defining answer options would grow the unexperienced interviewer's role too big and important. Un-structured interview, on the other hand, would be too loose for the purpose of this thesis as it would be difficult to categorise the interview data.

In more detail, a so-called theme interview method was decided to be utilised. The difference between it and the other semi-structured interviews is that in theme interviews the interview themes, of which the questions are formed, are the same in every interviews, not necessarily the questions [26, pp. 47–48]. This enables deeper conversations and more flexible interviews. However, it was important to ask rather same questions for all the interviewees, in order to be able to categories the data, compare the answers and find similarities between them.

An interview research has its own methods of processing and analysing the gathered data. There are three principal ways of analysing interview data:

1) Data is unpacked and directly analysed.
2) Data is first unpacked, then coded into classes and finally analysed.
3) Data is unpacked and coded simultaneously and then analysed. [26, p. 136]

In any of these three cases, analysis is started with unpacking the interview data, which usually means listening to the interview recordings and then writing them down, i.e. doing transcription. Depending on the nature of the research, transcriptions can be done with different accuracies – as some studies, e.g. discussion analysis, require very detailed transcribing of the recordings including all the pauses, sighs and emphases, some studies can be done with smaller accuracy. After the transcriptions are done, they are read through to get familiar with the data before analysing it.

Analysis of interview data can be divided into many different phases, its essential parts contain both analysis and synthesis [26, p. 143]. One way is to describe it simply as a process with three phases that are linked together, as presented in Figure 4.1.

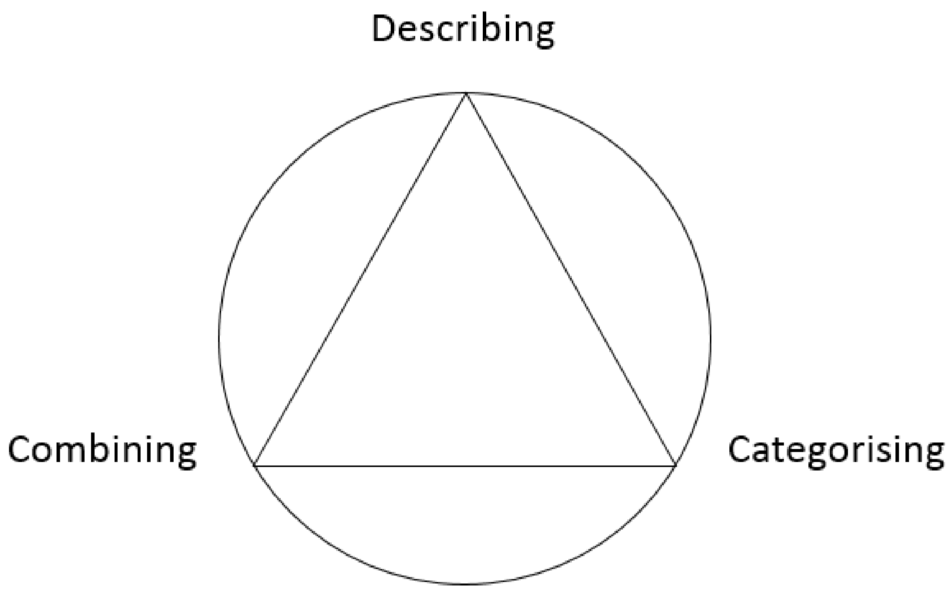

Figure 4.1. *A general three-phase analysis process of interview data. Adapted from [26, p. 145].*

The three general phases of the analysis of interview data presented in the Figure 4.1 can be described as follows [26, pp. 145–150]:

- **Describing the data:** the basis for the analysis. Aims to answer to questions such as who, where, when, how much and how often, in order to be able to find out the features and characteristics of people, incidents or objects. There are different kinds of describing, e.g. so-called *thick describing* aiming to describe comprehensively the studied phenomenon, and so-called *thin describing* which describes only facts.
- **Categorising the data:** the data is categorised into classes. The classes might be formed with the help of e.g. research problem, research method, classes used in earlier researches in the same field, etc. Categorising enables interpreting, simplifying and summarising the interview data. It also helps to structure the studied phenomenon to compare different parts of the data with each other.
- **Combining the data:** finding a regularity and similarity in the appearance of the formed classes of the interview data. By doing this some of the classes can be combined and the results of the study can often be improved and deepened. In some studies this phase is not needed.

The importance of these three phases differs depending on the research problem, strategy and the nature of the study. For instance, in some studies describing and categorising the interview data is enough and the combining phase is not needed. In some studies the interview data might be analysed by only describing it. [26, pp. 145–150]

The analysis provides interview results which are reported in a research report. The results are commonly presented in three alternating ways [26, pp. 169–170]:

1) As a written text, which might be direct or contain abbreviations, codes or interview quotes.
2) With the help of numbers, which could be presented within a text, in tables or in diagrams.
3) By displaying them graphically by utilising graphs, figures and diagrams.

In this thesis all of those three ways are applied. The interview results are mainly presented as a written text but also graphs and tables are utilised.

4.2 Text analytics

Text analytics (also known as *text mining*) refers to the methodology and process applied to derive quality and actionable information and insights from textual data. It is applied for operations such as *text categorisation, text clustering, sentimental analysis, similarity analysis and relation modelling,* etc. In more detail, popular text analytics applications are such as *spam detection, news articles categorisation, ad placements, chatbots,* etc. To succeed in these operations and applications, techniques from the fields of machine learning, linguistics and statistics are utilised. [56, ch. 1]

Text is unstructured data, and before it can be analysed with machine learning algorithms it has to be pre-processed into components with standard structure and notation, i.e. to make text analysable. Some of the most usual text pre-processing steps include the following [56, ch. 3]:

- **Tokenisation:** process of breaking down or splitting textual data into smaller meaningful components called *tokens*. Tokenisation means most usually either *sentence tokenisation* or *word tokenisation*. *Sentence tokenisation* is used for breaking down a text paragraph into sentences, which are further broken down into clauses, phrases and words with *word tokenisation*.
- **Tagging:** tags or annotations are added to text components to describe and to help to recognise them.
- **Chunking:** also known as *shallow parsing* or *light parsing*, a technique of analysing the structure of a sentence to break it down into its smallest tokens and group them together into higher-level phrases.
- **Stemming:** word endings or other affixes are removed or modified to merge word forms that differ in non-relevant ways. The output of a stem algorithm or a stemmer (programme) is called a stem, i.e. the base form of a word. For example, the base word ‘run’ can be formed into new words, like ‘runs’, or ‘running’, by adding

affixes to it. When stemming these words, a stemmer would give the base word 'run' as an output.

In this thesis text analytics, and in more detail *text classification,* is applied for developing a text classification tool in MS Excel, which functions as an alert signal categoriser. The texts to be categorised are alert signal descriptions from alert signal lists. This means the amount of needed text pre-processing is small. For instance, tokenisation is not needed as the words in signal descriptions are typically already pretty standardised and shortened. The idea is to develop a categoriser which sorts alerts from certain ship equipment into pre-defined groups by recognising the source of an alert from the alert descriptions.

4.2.1 Text classification

Shen defines *text classification* in [27] as a function that automatically assigns textual data into some pre-defined categories based on their content. Typical text classification applications are such where the goal is to identify small number of valuable documents within a large collection of unimportant documents – two common applications are, for instance, email spam identification and customer support [57, p. 891].

There are three common types of text classification: *binary classification*, *multi-class classification* and *multi-label classification*. Binary classification refers to a situation where documents are classified into one category of total two categories, e.g. an email is either spam or non-spam. Multi-class classification refers to a situation where there are more than two categories and the documents may be classified into one of them. Multi-label classification is for problems where each document can be given more than one category. [56, ch. 4]

The idea of text classification is shown in Figure 4.2.

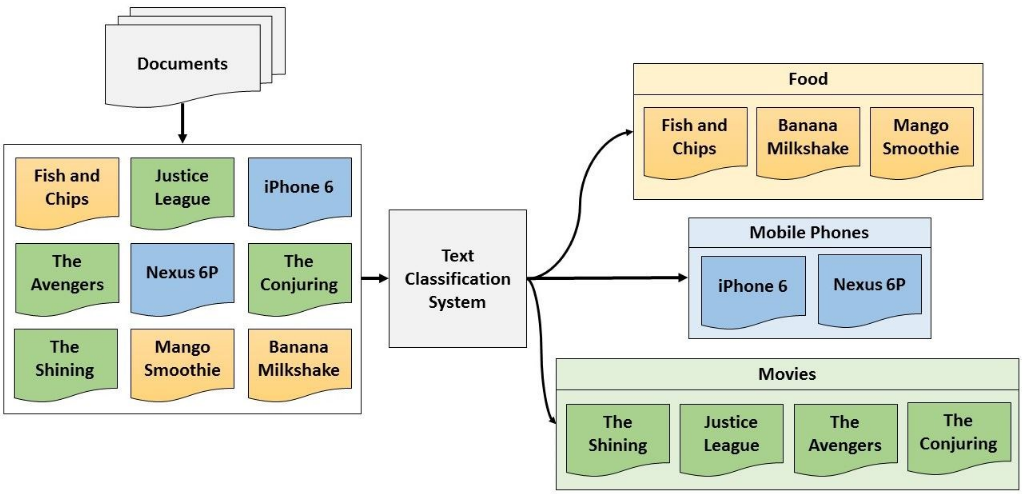

Figure 4.2. *The idea of text classification process. Adapted from [56, ch. 4].*

As seen in the Figure 4.2, the text classification system categorises every document from a group of documents into a specific and pre-defined category: documents assigned to different mobile phone brands and models are grouped under the class ‘mobile phones’, the ones assigned to various dishes under the class ‘food’ and the ones assigned to different movies are put into the class ‘movies’. Normally documents that are to be categorised with a text classification system are not as simple as in the Figure 4.2. Instead, they contain much more data which is also much more detailed. In addition, they might be categorised into groups of different levels, i.e. first into main groups and then further into subgroups [56, ch. 4].

Function of an automated text classification system is based normally either on *supervised* or *un-supervised machine learning algorithms*. As *unsupervised learning* refers to machine learning algorithms that do not require any pre-labelled training datasets for building a model, *supervised learning* refers to an opposite. The two main supervised learning algorithms are *classification*, i.e. a process predicting categories such as news categories or movie genres, and *regression*, an algorithm predicting continuous numeric variables, e.g. house prices or people’s weights. [56, ch. 4] This thesis focuses on the classification algorithm as its principles are applied in the later sections.

Building an automated text classification system can be divided into six main phases introduced in the following [56, ch. 4]:

1. **Preparing training and testing datasets:** training and testing text documents are gathered and training documents are manually given own corresponding categories. For instance, an alert from ballast water pump is given category ‘Ballast systems’ and a bow thruster alert ‘Side thrusters’.
2. **Text normalisation:** training and testing text documents are normalised. For instance, all alert signals might be converted to lower-case and all accent marks and numbers might be removed. This way e.g. ‘BOW THRUSTER1 ALARM” and ‘bow thruster2 alarm’ would be considered similar.
3. **Feature extraction:** meaningful features, e.g. numeric arrays or vectors, are extracted from the training and testing documents with different techniques.
4. **Model training:** the extracted feature vectors or arrays are fed for the training documents so that the learning algorithm learns various patterns corresponding to each category. This way the algorithm can predict categories for new documents to be classified. This results in a *classification model*.
5. **Model prediction and evaluation:** after the classification model is trained, the normalised testing documents are fed to it. Based on the previously learnt patterns, the model predicts a category for each testing document. After the prediction, the model performance can be evaluated by comparing the predicted categories with real ones and the model can be further trained to get better accuracy.

6. **Model deployment:** when all previous steps are finished, the built model can be taken into use.

In the development of the signal list categoriser later in this thesis the main principles of the six phases introduced above are applied. The goal is to categorise alerts from a signal list to pre-defined groups based on the ship functionalities and equipment. However, as the amount of textual data in a signal list – even in the biggest ones with tens of thousands of signals – is significantly smaller than in some real world applications, the developed classification system will not be as sophisticated as an automated system described above.

4.2.2 Utilisation of the SFI Group System

Before building a text classification system, the categories into which the textual data is to be grouped have to be defined. Generally, the more there are pre-defined categories the more complex the classification system becomes. In such cases the categories should be defined precisely to ensure proper functionality of the system.

Like introduced earlier, in this thesis the application for which text classification is used is alert signals lists of maritime vessels. The signals are wanted to be classified into main and sub-categories based on vessel functionalities and equipment, meaning the problem refers to the multi-label classification. Also, as vessels can be complex systems with numerous functions, the number of needed alert signal categories is big. That is why this thesis utilises the grouping methods of the SFI Group System, which is an international, standardised and the most used system for grouping ship equipment and components by their functions in the off-shore and maritime industry [28].

SFI Group System aims to accommodate all relevant ship types and to be a common code for the flow of information between different maritime enterprises. The system helps maritime industry, system and component suppliers as well as authorities to handle, for instance, specification, estimates, drawings, maintenance and repair planning, etc. In order to achieve this, the System provides a method to group ship equipment and components by their functions. These groups are called SFI Group System Main Groups and they can be seen in Figure 4.3. [28]

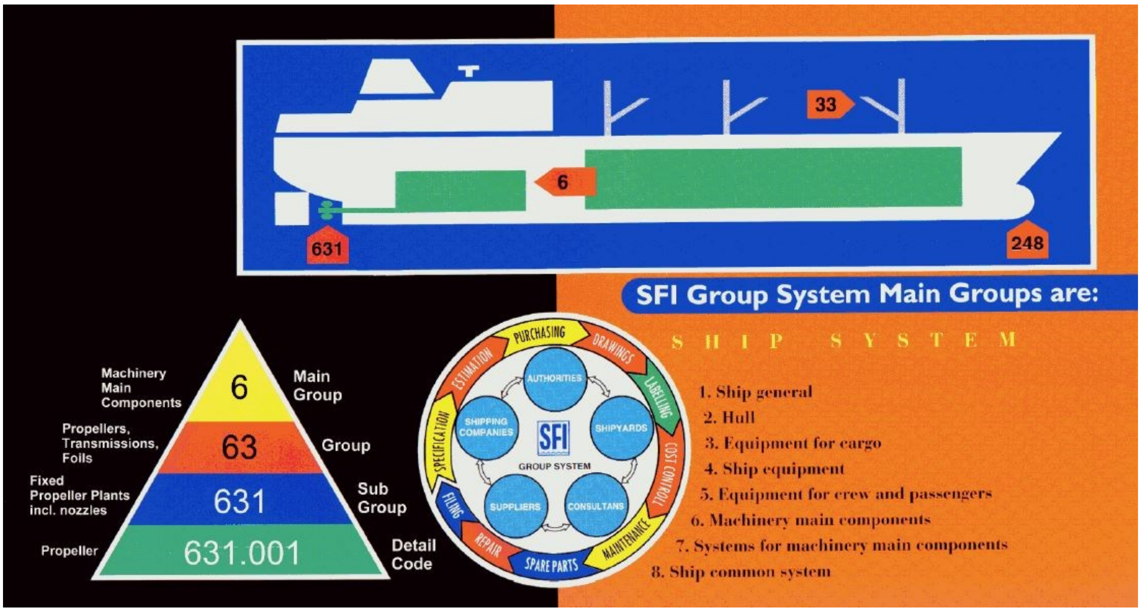

Figure 4.3. *SFI Group System main groups [28].*

The SFI Group System is a three digit decimal classification system, in which the ship is divided into 10 main groups from 0 to 9. Main groups 1–8 are named in the Figure 4.3 and main groups 0 and 9 are for users' free use, i.e. for components that are not covered in the SFI standard. Of these groups this thesis utilises main groups 2–8 and all their sub-groups, of which there are tens of in each. The main groups are described as follows:

1. **Ship general**: for details that are not any specific function on-board, e.g. general arrangement, launching or dry-docking.
2. **Hull**: hull, superstructure and material protection of the vessel.
3. **Equipment for cargo**: cargo equipment and machinery including systems for vessel's cargo, loading/discharging systems, cargo winches and hatches.
4. **Ship equipment**: ship specific equipment and machinery, e.g. for navigation, manoeuvring, anchoring, communication or fishing.
5. **Equipment for crew and passengers**: e.g. lifesaving equipment, furniture, catering equipment and sanitary systems.
6. **Machinery main components**: primary components in the engine room, e.g. main and auxiliary engines, propeller plant, boilers and generators.
7. **Systems for machinery main components**: systems serving machinery main components, e.g. fuel and lubrication oil, starting air, exhaust gas and automation systems.
8. **Ship common systems**: central ship systems, e.g. ballast and bilge, fire-fighting, wash down and electrical distribution systems. [28]

The SFI code's first digit defines the component's main group; in the Figure 4.3's example the digit and the main group is *6 – machinery main components*. The second digit is for the group; in the Figure 4.3's example the group is *63 – propellers, transmissions,* *foils*. The third digit is for the component's sub-group, which in the Figure 4.3 is *631 – fixed propeller plants including nozzles*. The detailed code, which in the Figure 4.3 is 001, defines the single piece of equipment. However, unlike the first three digits, the detailed component level coding is not standardised as the equipment of different vessel types and requirements to the code for shipyards and shipping companies vary [28].

Utilising SFI system is useful also for another reason, as the SFI codes can be applied when defining tags of alert and automation signals. If the vessel components and systems have been coded with SFI system, the same codes can be used in alert systems. When so, an alert tag for a single component could easily be given by adding an ISA function code to the component's SFI code. Examples of alert tag forming are given in Table 4.1.

Table 4.1. *Alert tag forming with SFI and ISA codes.*

Component SFI Code	ISA Code	Alert tag	Description
731.001	TAH	731.001_TAH	Starting air compressor 1 temperature alarm high
803.110	LAH	803.110_LAH	Engine room bilge level alarm high
404.106	PDAH	404.106_PDAH	Bow thruster 1 lubrication oil filter pressure difference alarm high

Even though the examples in the Table 4.1 are not from real life they illustrate how the tagging could be done. As the SFI groups have their own numbers, categorising alerts into them might come useful if also component codes and alert tags are needed to define.

5. IMPLEMENTED INTERVIEW STUDY

In this chapter the implemented interview study is discussed. The aim of the interviews was to answer the first research question of this thesis, i.e. ‘How do alerts and alert systems variate between different maritime vessel types, vessels and alert system suppliers’ products?’ The results of this section are used as a starting point in the next section of this thesis.

Interview was chosen for data gathering method due to complexity of the research question that is aimed to be answered. By interviewing people with experience in maritime vessels and their operations, a broad range of different vessel types and alert systems can be covered. As mentioned in the section 1.4, interview itself is also an effective way to collect research data.

At first, in sub-chapter 5.1, the carried out interviews are presented, i.e. the interviewees and the utilised interview themes are introduced. This is followed by sub-chapter 5.2 in which the analysis of the gathered interview data is gone through. Lastly, in section 5.3, the interview results are presented.

5.1 Semi-structured theme interviews

In total four maritime industry experts were interviewed during the spring 2018. This included one chief engineer and three officers, of which two had worked as first mates and one both as a captain and a pilot. All the persons chosen to be interviewed were found inside the company for which this thesis is done for, meaning the arrangements were easily done. The number of interviewees was kept relatively low due to the scope of this thesis and to the fact that the gathered data was sufficient for providing satisfying results.

The interviews were carried out in semi-structured form, as so-called theme interviews, and the data was collected by recording the conversations. The interview language was Finnish, as all the interviewees and the interviewer were its native speakers. The question frame, i.e. themes, was similar in all interviews and the same main questions were asked in every interview. However, the order and wording of the questions variated between different interviews. This was due to the interviewer’s intention to keep the interview situations relaxed and somewhat informal and also to the fact that the conversations often went into such directions that a pre-defined question order would not have felt natural. In addition, sometimes the interviewee might have answered to an upcoming question already when answering to another question.

In the interviews, the following themes were carried out:

1. Professional background & experience in different vessel types
2. Experience in automation & alert systems
3. Knowledge of variations in different vessel types
4. Roadmap for development of an intelligent alert system

Before the interviews, a question frame about these themes was made in Finnish. It can be found in the Appendix A. With the questions of the first theme the professional and educational background of the interviewee was clarified. Questions in the second theme tried to, for instance, find out what kind of differences there are between different manufacturer's products and if there are correlations between some vessel types and alert system brands. In the third theme, questions dealt with differences and similarities between vessel types and vessels within specified vessel types. This was mainly done in the point of view of the sub-systems and level of automation on board. Questions in the last theme were simple as the interviewees were directly asked which vessel types they would suggest to start the development with. The questions were straight, since all the interviewees gave ideas regarding the development roadmap already when answering to the questions of earlier themes.

Like said, the question frame was not always followed slavishly and additional, clarifying questions were often asked. Furthermore, some questions had to be repeated, sometimes in a different way, since the interviewee might have answered somewhat off the subject. This all resulted in good conversations in which knowledge was received also on other themes than the four presented above.

5.2 Analysis of interview data

The analysis of the gathered interview data was started by first listening to the recordings and then writing them down, i.e. making transcriptions. Since the objective of this interview study was not to do conversation analysis, perfectly accurate transcriptions were not needed. Thus, for instance pauses, laughs and sighs and situations in which the discussion drifted off topic, were not written down. Otherwise the transcriptions were made word-for-word to the best of the thesis writer's ability. This was due to two reasons:

1) To capture confident and insecure answers in order to help the further analysis of them.
2) To enable possible future usage of the gathered data.

Since the number of interviews, and thus the size of the gathered data, was moderate, some of the main ideas of the answers were understood already in the transcription phase. However, after the transcriptions were done they were read through couple of times to further acknowledge the messages the interviewees gave. After that, the main ideas of the transcriptions were described. The descriptions were simple, for instance of the following type: ‘In the opinion of the interviewee 1 all the vessels equipped with a DP system have a lot of problems with alert management.’

After describing the main ideas of the data, it was for its most relevant parts categorised into classes based on the themes presented in the section 5.1. Even though the classes were based on the interview themes, the division was not automatic: some answers fit into more than one classes, so the data had to be carefully studied to find out what really answered to what.

In this study combining the classes was not seen necessary. Thus, after the data had been divided into the classes it was summarised and processed into common Finnish to make the text more readable for the further use. This required, for instance, shortening sentences with words repeated in a sequence and standardising dialectal speech. Couple of examples of the original interview answers and their processed versions (in Finnish) as well as their English translations are seen in the Table 5.1.

Table 5.1. *Examples of interview answers and their processed and translated versions.*

	Example 1	**Example 2**
Word-for-word transcription	“Mun tausta on se, et mä oon ollu, tota noin niin, Nesteel tankkereis, sekä kemikaali- et tota noin niin, raakaöljytankkereis, ja sit mä olin kans nois, tota noin niin, LNG-tankkereis, elikkä oikeestaan kaiken tyyppisissä tankkereissa ollu.”	”No ihan varmasti olis, et kyl mä väitän, et kaikki, kaikki kiittäs, ketkä on sillal työskentelee, jos siin ois joku sellanen, et kaikki laitevalmistajat tekis samal taval sen. Ja just se, et ois ne eri äänet, jos on niin ku vakava juttu ja jos ei.”
Processed Finnish version	”Olen työskennellyt Nesteellä kemikaali-, raakaöljy- ja LNG-tankkereissa, eli oikeastaan kaiken tyyppisissä tankkereissa.”	”No ihan varmasti olisi. Väitän kyllä, että kaikki komentosillalla työskentelevät kiittäisivät, jos se menisi niin, että kaikki laitevalmistajat tekisivät sen samalla tavalla. Ja juurikin niin, että olisi eri äänet, jos on vakava tilanne ja jos ei.”
English translation	“I have worked at Neste on chemical, crude oil and LNG tankers, so basically on all types of tankers.”	“Surely it would be so. I swear everyone working on the bridge would be thankful if it was so that every system manufacturer would do it similarly. And also if there were different sound indications for severe and non-severe situations.”

As it is seen in the Table 5.1 the processed versions are shorter and more readable than those word-for-word versions. Especially the message given in the example 1 could be summarised in a brief form as it is much simpler than the message of the example 2. In addition, the answers have been interpreted so that some ‘non-said words’ have been added, e.g. from ‘sillalla’ to ‘komentosillalla’, and some dialectal expressions have been changed, e.g. from ‘vakava juttu’ to ‘vakava tilanne’. These kinds of modifications help the answers to express their contextual meanings even when quoted on their own.

When the data was processed the different answers within the pre-defined classes were compared to each other in order to find similarities and differences and also regularities and frequent themes. This resulted in the capability of making conclusions and answering the targeted research question of this section.

5.3 Interview results

As introduced earlier, the first class of the interview data was the interviewees' backgrounds and experiences in different vessel types, as the second one was the interviewees' experience in different maritime automation and alert systems. These first two classes do not really answer the research question but mainly build the foundation for the last two classes. The intention was to ease the evaluation of the later answers and finally the main interview results. Since the objective is to compare different vessel types, the interviewees' experience in that area was seen important. The main results of the first class are summarised in Table 5.2.

Table 5.2. *Interviewees' experience in different vessel types.*

Vessel type	**Person 1**	**Person 2**	**Person 3**	**Person 4**
Passenger	x		x	x
Cargo: container & bulk carrier	x	x	x	x
Ro-Ro	x		x	x
Tanker: chemical, crude oil, product & LNG		**X**		x
Off-shore supply		**X**	x	
Anchor handling		x	x	
Tug			**X**	x
Icebreaker: traditional & multipurpose			x	**X**
Cable layer			x	

The Table 5.2 points out that a wide variety of different vessel types is covered. Passenger ships, Ro-Ro vessels and different types of cargo ships were the three types that the most interviewees had experience in. If an interviewee had clearly some vessel types that he or she had the most experience in, they are marked with capitalised and bolded x letters. In addition, if an interviewee had very short experience in some vessel type, it is not mentioned in the table. Worth noticing is also that one interviewee, Person 4 in the Table 5.2, had worked for 13 years as a pilot and said having piloting experience 'basically in all types of vessels'.

According to the data grouped into the second class, the interviewees' had experience in automation and alert systems from many different suppliers, such as Kongsberg, ABB, Metso, Praxis and Wärtsilä. Apart from old ones, the systems were seen somewhat similar from the point of view of the basic functionalities and operation. The main operational differences were in how alert data was shown, e.g. what kind of information was visible: for instance, as Kongsberg's system told what the problem is in more detail, ABB's system gave only a number of series with which the details had to be checked either from the user manual or from the alerting equipment itself. Kongsberg's systems were seen more developed in other senses too, as they had some kind of alert management functions, such as alert prioritising and filtering, which the other systems did not really have.

Alert systems in general were seen quite un-intelligent as they had little or no alarm management features in them. A frequent message of the interviewees was that prioritisation and filtering should be added to them to make the vessel operation more convenient and even safer. Alarm flooding and frequent alerting of unimportant alarms leading to careless operations was seen as a real problem. The interviewees felt that there would be a real need for more intelligent alert systems, especially in modern and complex vessels with many sub-systems and a high level of automation. One interviewee had also been familiarised to a modern nuclear power plant alert system with intelligent alarm prioritisation and hoped a same kind of approach to the vessel alert systems too. In addition, lack of standardisation in the systems was seen problematic, which indicates that the IMO's recommendations, mainly the CAI and BAM, are not really followed in practise.

The questions in the third class, i.e. about differences in vessel types and vessels, resulted in rather complex answers. At first, they pointed out that vessels are generally always individuals and even sister vessels might differ completely from each other, as they are often designed according to requirements given by the future crew. That is why it was also tried to clarify what kind of similarities there are between vessels and vessel types. However, the answers provided knowledge which helped to make conclusions about those variations.

According to those answers, the principle is that the simpler the vessel type is the less there are variations between the vessels in that type. Simple here means small amount of systems and sub-systems on board, meaning small number of automation I/Os, i.e. low level of automation. Differences and similarities between vessels of different vessel types depends totally on the operational purpose. These answers can be analysed with the help of figure 5.1, which is adapted from the reference [48, p. 28].

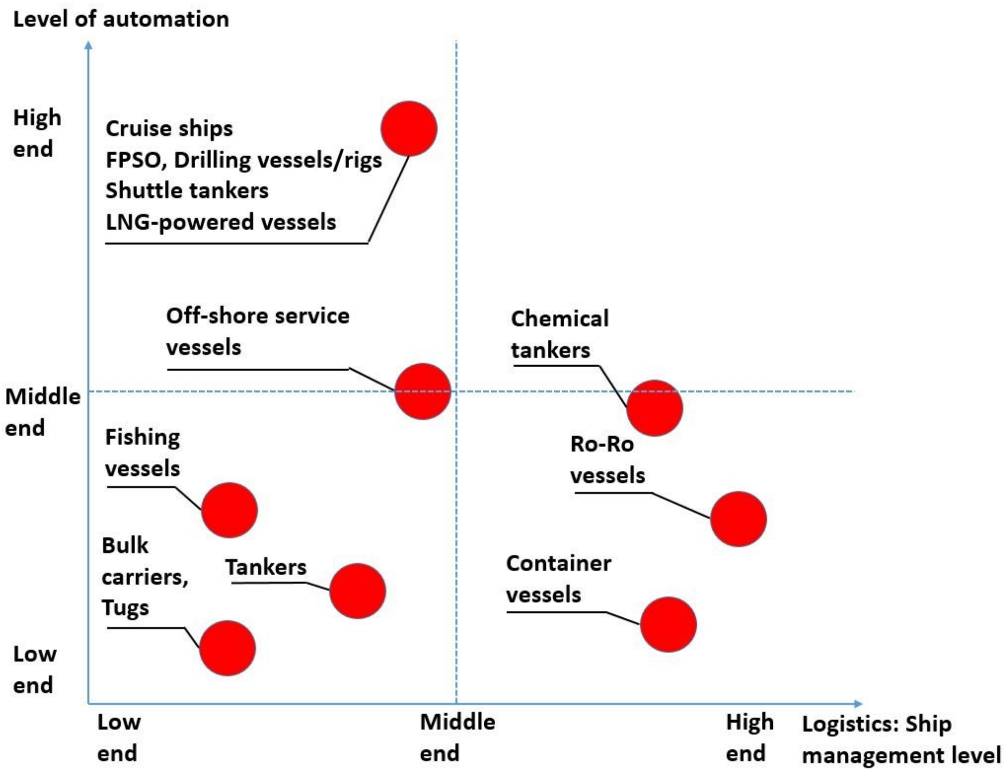

Figure 5.1. Complexity of various vessels. Adapted from [48].

In the Figure 5.1 the vertical axis demonstrates the level of automation so that the more there are I/Os in the automation system of a vessel type, the higher it is placed vertically. As can be seen, the vessels with highest level of automation are cruise ships, floating production and storing units (FPSOs), drilling vessels, shuttle tankers and LNG-powered vessels. According to the interviews these would be the vessels with more variations in them and the vessels with small variations would be bulk carriers, tankers, containers and also tugs, which came out in the interviews. This makes sense, as if there are e.g. 30 000 I/Os on a cruise ship and 3000 on a bulk carrier, there has to be thousands of signals totally differing from each other. On the other hand, if e.g. 50 % of I/Os of two large cruise ships were somewhat identical, 25 % had something in common and the rest 25 % were completely different, the variations in I/Os and thus alerts would be numerically massive. The same percentages on a bulk carrier with 3000 I/Os would be numerically much more comprehensible.

The fourth and the final theme, i.e. recommendations for the roadmap of development of an intelligent alert system, was seen a bit problematic and answers of three kinds were given. One interviewee thought that tankers could be a good starting point. This was due to quite standard structure of them and to strict safety standards regarding the many times hazardous and polluting cargo. According to the interviewee, tankers in general have very same kind of functionalities and operations and also very many measurements and strict supervision of the cargo contents. Since the operations in general are quite identical between different tankers, the measurements and alerts are also similar on them. Also, as a result of the numerous measurements and the strict supervision, there are numerous alert points and active alerts, meaning that an intelligent alert system could be useful.

One interviewee told that traditional tugs are normally very similar to each other, as they have very simple structure with a main engine, a conventional propulsion chain and a shaft. However, the interviewee was of the opinion that an intelligent alert system would be quite useless in the simplest vessel types and suggested to start from some slightly more complex types with more automation on them. An off-shore supply vessel was one type the interviewee proposed, as they are quite simple in structure but also have modern systems, such as dynamic positioning, causing problems with alerts.

The two rest of the four interviewees suggested a different approach, as they were of that opinion that the vessel type does not necessarily make difference between similarities. They proposed studying fleets of big shipping companies and finding out if there would be big series of vessels. They had personally experienced that large shipping companies, in this case Neste with its tankers and a German cargo company with cargo ships, try to make vessels in same series more and more similar to each other. This is due to mainly two reasons, of which the first one is to achieve cost savings and the second to ease the crews' work in situations where they switch from one vessel to another.

6. DEVELOPMENT OF AN ALERT SIGNAL LIST CATEGORISER

One of the goals of this thesis was to suggest methods for taking the variations in alert systems into account when designing an alert system customisable for various vessel types. This was summarised in the third research question of this thesis: ‘In which ways could a vessel alert system be optimally customised for various vessel types with respect to needed amount of work?’ In this chapter that question is aimed to be answered by developing a signal categorising tool in MS Excel. It is designed to group the alert signals into pre-defined groups based on the vessel machinery and functionalities.

The challenges the alert variations cause for alert system design are analysed in section 6.1. This is followed in sub-chapter 6.2 by description of the design and basic functional description of the signal list categoriser. This is followed by sub-chapter 6.3, in which the categoriser is trained and tested with couple of real-life automation and alert signal lists.

6.1 Challenges of alert variations

Based on the knowledge and results gained in the literature review and conducted interviews, the variations in vessel alerts and alert systems can be rather diversified. In general, alerts on a certain vessel type, at least on a vessel without a high level of automation and auxiliary systems, originate from same basic functions, such as tank pressures, pump failures etc. On the other hand, the way of presenting the alert data, e.g. alert tags and descriptions given to the signals, differs a lot. For instance, in one system’s alert descriptions an azimuth thruster might be abbreviated as ‘Azm. Thr.’ and have an equipment tag of ‘404-301’, as in another system it might be called ‘AZI THRUST’ and have a tag of ‘6351’.

The differences described above can originate from many sources. For instance, one shipyard might use SFI Group System for grouping and identifying vessel functions and equipment and thus give an azimuth thruster ‘404-301’ for an equipment tag, while the other shipyard has its own identifying system and accordingly tags the same equipment with ‘6351’. The variations in alert descriptions, on the other hand, might be due to differing preferences of different automation system designers – one might just like to abbreviate ‘azimuth thruster’ differently than the other, which is enough to make the difference in every azimuth thruster alerts between the two vessels.

The variations like described above are problematic when developing an alert system that is intended to be both a retrofit installation and customisable for various vessels and vessel types. Such alert system should be able to utilise signals from various existing vessel systems. In addition, as explained in the section 4.3, when developing intelligent alert system functions, such as alarm filtering, grouping and suppressing, the alert signals are needed to be categorised into different groups. As alert signal lists can have hundreds or thousands of signals, the grouping is a demanding task. This is especially the situation if the grouping is to be done manually. That is why simple examples of how the customisation work could be done with less manual effort were wanted as a product of this thesis.

6.2 Design

A simple alert signal list categoriser, later referred as 'the categoriser', was developed to overcome the challenges described in the section 6.1. The idea was to utilise methods of text analytics, in more detail text classification, to automatically group alert signals into pre-defined groups. As the objective was to provide simple examples to answer the challenges the alert variations cause, and due to the limits of the scope of this thesis, the goal was not to develop a perfectly functioning solution solving all the problems. Instead, the categoriser was developed to be some sort of a prototype that could later be updated by the users.

The categoriser was decided to be implemented in MS Excel. This was due to four main reasons. Firstly, automation signal lists are normally Excel spreadsheets, meaning that doing the categorisation in Excel helps to avoid additional work, i.e. converting files from one programme to another, e.g. from Excel to Matlab and back to Excel. Secondly, Excel is widely used, meaning that the categoriser made as a simple Excel solution could be easily adopted by different users. Thirdly, Excel enables creating own macros with Visual Basic for Applications (VBA) programming language, which helps to make the categoriser function more automatically. And lastly, as the categoriser was to be developed so that it could be updated by its users, a common platform that many people can use was chosen. In addition, the fact that the developed categoriser can be utilised for grouping all kinds of automation signals, justified the use of MS Excel.

6.2.1 Signal categories and functional principles

In text classification textual data is classified into pre-defined categories based on their content. In the context of this thesis, the textual data is alert signal descriptions and the categories it is classified into are ship functions and equipment. To define the signal categories, the SFI Group System's groups introduced in the section 4.2 were decided to be utilised. This was argued for two reasons: firstly, defining the groups for a text categorisation process can be a time-taking and demanding task – using an existing system eases the development work. Secondly, the SFI Group System is internationally the most widely used classification system grouping ship equipment and functions, which helps the categorisation as some ships and alert systems are built with it. Additionally, if an alert system is to be customisable for wide variety of vessels, a standard solution is useful

However, as the total SFI Group System installations since 1972 is no more than somewhat over 6000 [58], it is not that covering solution considering the size of the global fleet of approximately 90 000 vessels. Still, utilising it was seen reasonable and beneficial.

The categoriser aims to classify each alert signal of the processed signal list into one of the SFI System's main groups from 2 to 8. Furthermore, each alert signal is also given a more detailed SFI sub-group. For instance, an alert from an opening watertight door would be grouped into the main group of '*2 – Hull Systems*' and further into sub-group of '*209 – Watertight bulkheads w/stiffening*'. More such examples are given in Figure 6.1 below.

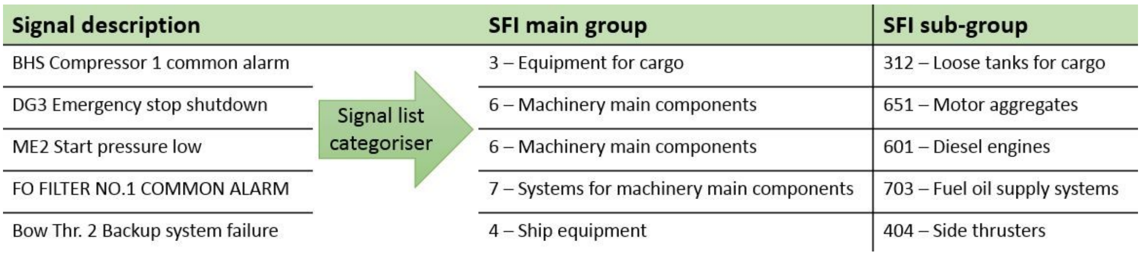

Figure 6.1. *Alert signal categorisation examples.*

The Figure 6.1 shows an abstraction of the categoriser's basic function with alert signal examples from different real-life alert signal lists. The main target is to find SFI main groups for the signals in order to help to classify the alerts into the groups that are needed for the development of an intelligent alert system. In the found SFI main group the categoriser finds also a sub-group, but since there are tens of them in a main group, resulting in hundreds of them in total, the findings are more of suggestions and should not always be blindly trusted.

As the categoriser utilises methods of text classification, signal descriptions was an obvious choice for the signal metadata to be utilised in the classification. Other utilisable metadata with which signals might be categorised could be e.g. signal types, measurement values and hierarchy level of the alerting automation equipment. They could be utilised in the implementation of the categoriser so that in the given SFI groups the signals could further be categorised by their hierarchical levels, measurement values or signal types, etc. However, as the purpose was to develop a simple solution such features were not implemented in this work.

The categorisation is based on keywords attached to each SFI main groups. There is a datasheet in the categoriser Excel workbook, in which the keywords representing vessel functions and equipment of the SFI main groups are filled. The keywords are assembled by studying various alert lists to make the dataset as comprehensive as possible. This can be considered as the manual training of a text classification system, which was described in the chapter 4.2. Table 6.1 gives examples of vessel equipment and keywords attached to them.

Table 6.1. *Examples of vessel equipment and their keywords and SFI groups.*

Equipment	Keywords	SFI main group	SFI sub-group
Azimuth thruster	Azimuth thr Azi thr Azm thrust	4 – Ship equipment	404 – Side thrusters
Starting air compressor	Start air compr SA compressor SA compr	7 – Systems for machinery main components	731 – Starting air systems (high pressure)
Lubrication oil separator	Lube oil separator Lub oil separ LO sep	7 – Systems for machinery main components	712 – Lube oil purification plants

The examples given in the Table 6.1 explain how the keywords in general are formatted – they are basically vessel functions and equipment written in many different ways. Thus, also use of imagination and common abbreviations of certain machinery and equipment can be utilised when adding more keywords to the dataset to make it more comprehensive. This means that the categoriser can be trained without alert signal lists too.

The categoriser's function is based on a simple algorithm comparing signal descriptions to the keyword dataset. It is explained in five steps in Table 6.2.

Table 6.2. *A Five-step description of the signal list categoriser's function.*

1. The description of the processed alert signal is compared to the keyword dataset.
    - For pre-processing, all the letters of the description and keywords are capitalised. This way e.g. 'MAIN ENGINE' and 'main engine' are considered similar.
2. All matching keywords are found, if none is found the alert signal is not categorised.
    - A keyword matches a description if it is totally included in the description, e.g. a keyword 'azim' matches a description 'azimuth thruster…' but a keyword 'azm' does not.
3. If more than one matching keywords were found, the keywords are arranged so that the first found comes first, second found second, and so on.
    - In most cases no more than one keyword is found and finding more than two is unlikely.
4. The alert signal is grouped based on the SFI data of the first found matching keyword.
5. If more than one matching keywords were found, the alert signal is given a suggestion for an alternating SFI sub-group based on the first keyword with different SFI data than the first found keyword.
    - If the second found keyword has the same SFI data as the first, the suggestion is given based on the third (if there is such) and so on.
    - If all found keywords have the same SFI data, no suggestion for an alternating sub-group is given.

As explained in the table 6.2, the function of the categoriser is rather simple. As the descriptions are initially somewhat normalised text, the only pre-processing done is capitalising the letters of the description and keywords. In addition, the categorising algorithm is implemented so that a keyword has to be totally included in a description for a match to occur. This is due to alert messages that normally contain a lot of abbreviations of different lengths – defining a universal threshold value for a match would be challenging. The categorisation is also based on the first found keyword, as alert messages are usually formed so that the alert source is indicated at the beginning of the description. However, if another keyword with different SFI data matches to the description, a suggestion for an alternating SFI sub-group is given. This gives the user is an option to re-evaluate the categorisation.

The categoriser is implemented so that it can be continuously trained more effective. This can be done, for instance, when a matching keyword for an alert cannot be found automatically and the categorisation has to be done manually. In that case, the user could update the keyword dataset with data taken from the description of the signal that the categoriser could not classify. By doing this, the categoriser should function more effectively after every time it is used, meaning the alert variations are taken better into account.

Knowledge of vessel systems, machinery and equipment is useful when training the categoriser. For instance, interpreting alert lists can be difficult without that kind of knowledge, as system names are often shortened into abbreviations of couple of letters, e.g. 'sea water pump' might be 'SW pump' and 'hydraulic power unit' simply 'HPU'. Thus, utilisation of literature is recommended when training the categoriser. An excellent reference for that purpose is, for instance, *Wärtsilä Encyclopedia of Ship Technology* by Jan Babicz [32].

6.2.2 MS Excel implementation and operational description

The developed categoriser is an Excel workbook consisting of four sheets, a main page called '*Main page*', a sheet for keywords with their corresponding SFI groups called '*Keywords*', a sheet containing all the SFI sub-groups called '*SFI*' and a sheet providing user manual called '*User manual*'. The categoriser was implemented by programming and utilising macros that run the code that executes the signal grouping.

In the following, the structure and basic operational description of the categoriser is gone through with screenshots taken from the categoriser Excel workbook. Some of the screenshots referred in the text can be found in the Appendix B. At first, Figure 6.2 shows the Main page of the signal list categoriser.

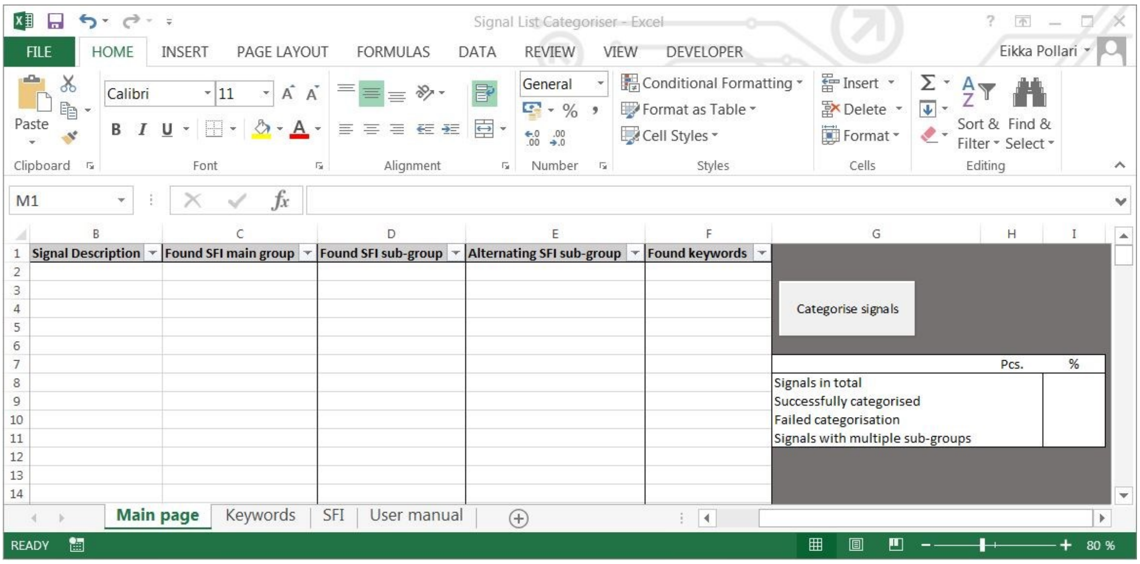

Figure 6.2. *Main page of the signal list categoriser.*

The Main page shown in the Figure 6.2 contains one command button, five visible columns and a table providing basic statistics of the categorisation results. Of the five visible columns, the column B, '*Signal Description*', is the one where the user adds the signal descriptions of the alerts to be categorised. The command button '*Categorise signals*' located on the right runs the macro that categorises the added signals. After the macro is executed, the other four columns are automatically filled. Column C, '*Found SFI main group*', is where the found SFI main group and corresponding number come. Column D, '*Found SFI sub-group*', works in the same way as column C, but for the SFI sub-group and sub-group number.

Columns E and F are meant for helping to evaluate the categorisation results. If the categoriser finds more than one SFI sub-group, one alternating (the first one found) is put with the corresponding sub-group number in column E, '*Alternating sub-group*'. Colum F, '*Found keywords*', is filled with all the keywords the categoriser found in the processed signal description. This data helps the user to judge if the categorisation is correct – many found keywords and an alternating sub-category suggest that the categorisation result is insecure and it should be checked manually. To help the evaluation, some basic statistics of the categorisation are filled in a table located under the '*Categorise signals*' command button. These include the number of processed signals and the number and the percentage of successfully categorised signals, failed categorisation and signals with multiple suggested sub-groups.

For the purpose of evaluating the categorisation accuracy, the categoriser highlights the columns from B to F automatically with different colours, according to the categorisation result. This is illustrated in Figure 6.3.

Signal Description	Found SFI main group	Found SFI sub-group	Alternating SFI sub-group	Found keywords
PS ME POWER LIMITATION ACTIVE ((	6 - Machinery main components	601 - Diesel engines	-	ME
PORT MAIN ENGINE COMMON ALAR	6 - Machinery main components	601 - Diesel engines	-	Main engine
PS ME FO FILTER DIFFERENTIAL PRES	6 - Machinery main components	601 - Diesel engines	703 - Fuel oil supply systems	ME & FO filter
PORT SRP SYSTEM MAX. HYDR. OIL T	6 - Machinery main components	634 - Controllable pitch propeller plar	-	SRP
PORT GENERATOR 24V DC CONTROL	6 - Machinery main components	625 - El. generator/el. motor plants	866 - Batteries & chargers	GEN & DC
PORT GENERATOR COMMON ALARN	6 - Machinery main components	625 - El. generator/el. motor plants	-	GEN
PREFERANTIAL TRIPPING	Category not found	Category not found		
ER FO UNITS EM. STOP ACTIVATED	7 - Systems for machinery main c	703 - Fuel oil supply systems	812 - Emergency shutdown s	FO Unit & EM. STOP
Em. Transf. 1 690/230VR Phase Tem	Category not found	Category not found		
AZI1 THRUST LO PUMPS NOT RUN	4 - Ship equipment	404 - Side thrusters	-	azi
DG4 SHUTDOWN	6 - Machinery main components	651 - Motor aggregates	-	DG

Figure 6.3. *Examples of categorisation results.*

As shown in the Figure 6.3, if the categoriser cannot find a group for a signal, columns C and D are filled with text '*category not found*', and all the columns from B to F are also highlighted with red colour. Otherwise the columns are highlighted either with green or yellow colour – green for successfully categorisation and yellow for signals with an alternating SFI sub-group suggestion. This helps the user to evaluate the categorisation results and to notice the failures quickly, especially if there had been very many signals to be grouped.

The sheet '*Keywords*' is where the user can train the categoriser to improve its efficiency. A screenshot of the Keywords sheet is shown in Figure 6.4.

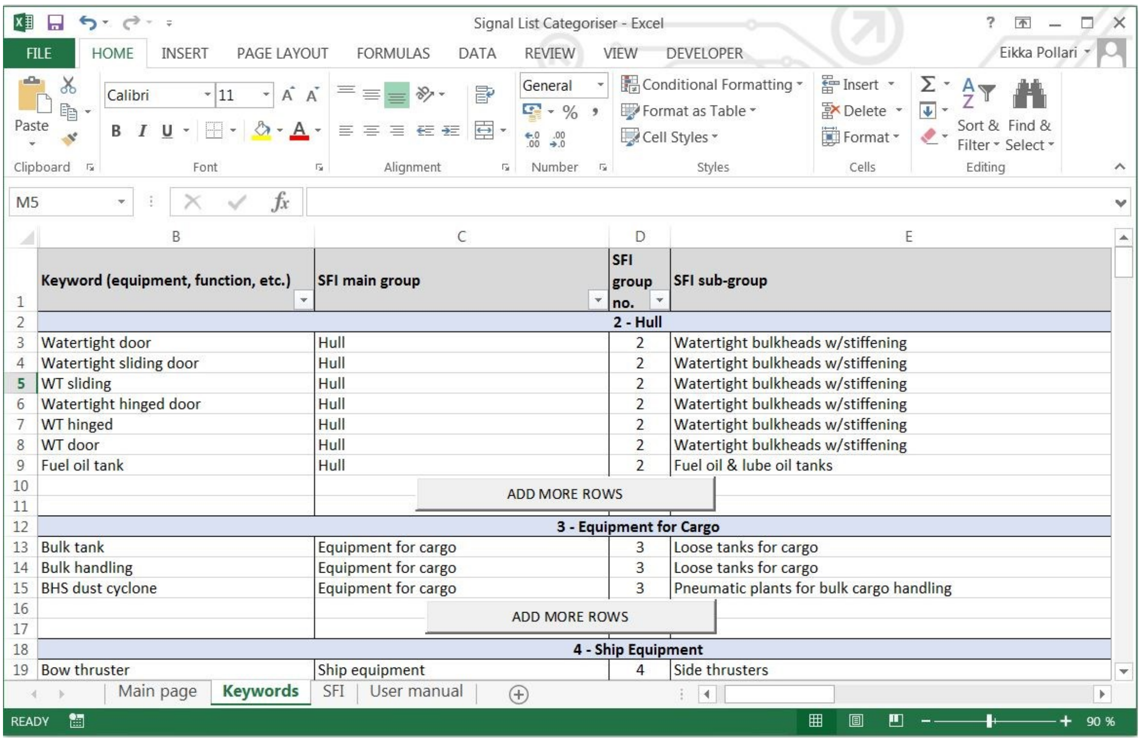

Figure 6.4. *Keywords sheet of the signal list categoriser.*

As the Figure 6.4 shows, the Keywords sheet has own sections for the SFI main groups (the groups 4–8 are not visible in the Figure). Each of the SFI main group sections have also an own command button, '*ADD MORE ROWS*', for adding a new row to the section when clicked. The purpose of the sheet is to contain all the keywords that are utilised in the categorisation, they are located in column B.

As in the Main page, the functions in the Keywords sheet are tried to make as automatic as possible. When the user wants to add new keywords, the command button '*ADD MORE ROWS*' is to be pressed. That executes a macro that adds a new row in which columns C and D are automatically filled with the corresponding SFI main group and SFI group number of that section. After the new row is added, the new keyword can be filled in the column B. Then the SFI sub-group can be chosen from a drop-down list in column E. After the sub-group is selected, a corresponding sub-group number is filled automatically in the column F of the added row. This is achieved by utilising the *Index* and *Match* functions of Excel. This functionality is presented in Figure B.1.

The third sheet of the categoriser is named 'SFI' as it contains all the SFI sub-groups. It is where the SFI sub-group and sub-group number are retrieved when the user adds a sub-group for an added keyword. A screenshot of the SFI sheet is shown in Figure B.2. As it is seen in the Figure B.2, the SFI sheet of the categoriser workbook is simply containing all the functions and equipment and their SFI sub-group numbers of each of the SFI main groups 2–8. The data in this sheet is not meant to be updated and its only purpose is to assist the automatic functions of the Keywords sheet.

The purpose of the fourth and the last sheet, 'User manual', is to instruct the user to utilise the functionalities of the categoriser. As the manual is included in the same Excel workbook, it is easily reached when needed. The aim is that anybody could use the categoriser with the help of the manual. Therefore the sheet contains step-by-step instructions with detailed figures. Screenshots of the 'User manual' sheet are shown in Figures B.3, B.4 and B.5.

6.3 Performance tests and results

The developed signal list categoriser was tested with four signal lists of various sizes from real-life projects and vessels. The tests were done two times: after the first attempt the keywords were updated with the data of the signals for which the categorisation was not successful and then the categorisation was redone with the same list. The purpose was to test the function of the categoriser and to demonstrate how it can be taught more effective by adding more keywords in it.

The first alert signal list was an extract of alerts of an icebreaker, containing 36 different alerts in total. The second one was a list of machinery and engine alarms of total 264 signals. The third list was a large list of 910 alerts and finally a list of 1520 signals was categorised as the fourth test list. The initial keyword dataset consisted of 151 different keywords. The results are presented in Table 6.3.

Table 6.3. *Test categorisation results at first attempt.*

	Case 1	Case 2	Case 3	Case 4
Number of signals	36	264	910	1520
Successfully categorised	26 (72.2 %)	129 (48.9 %)	706 (77.6 %)	1083 (71.3 %)
Failed categorisation	10 (27.8 %)	135 (51.1 %)	204 (22.4 %)	437 (28.8 %)
Signals with alternating sub-group	2 (5.6 %)	2 (0.8 %)	53 (5.8 %)	85 (5.6 %)

Table 6.3 contains four kinds of results: number of successfully categorised signals, number of signals that could not be categorised and amount of signals that were given an alternating SFI sub-group suggestion. The results in the Table 6.3 are rather satisfying: the least accurate categorisation was done in case 2 and even it was reasonably good with 51.1 % of all signals successfully categorised. For all of the other three lists the same number was over 70 %. In addition, the percentages for signals with alternating suggested sub-groups were reasonable for all the signal lists. Surprising was that bigger lists, i.e. cases 3 and 4, got good results already with the first attempt. However, after reviewing those lists more closely it was realised that they had a lot of signal descriptions that were basically duplicates of each other. For instance, there might be four dry bulk tank, each having 10 different alerts, meaning there were 40 alerts in the signal list which had rather similar description. Also, the initial keyword dataset was mainly build by reviewing those two lists.

Before the second attempt of the test categorisation, the failures of the first attempt had to be analysed. Certain was that at the first attempt the size of the keyword dataset was not very large with 151 keywords in it and therefore plenty of new keywords were expected to be added.

That was also the case, as more than 100 new keywords were added to the dataset. Even though the numerically biggest amount of failures were got with the alert list of case 4, most of the added keywords were derived from the list of case 2. This was due to fact that many of the failures in both cases 3 and 4 were duplicates, meaning that adding one keyword could add several new successfully categorised signals to the results. In addition, most of the failed signals of case 3 were such that they could not be interpreted and therefore not so many keywords were added based on the results got with that signal list. In addition to the added new keywords, also several old ones were deleted as they proved to be useless. These modifications resulted in a keyword dataset of 242 keywords.

After the modifications were done, the categoriser was re-tested with the same alert lists. Now it could be expected that all the signals of case 1 should be successfully categorised, and also cases 2 and 4 should get good results. As most of the unsuccessfully categorised signals of signal list of case 3 were such they could not be interpreted, not very big improvement was anticipated for that case. Uncertain was how much the much bigger keyword dataset would cause categorisations with alternating sub-groups. The results of the second attempt of the test categorisation are presented in Table 6.4.

Table 6.4. *Test categorisation results at second attempt.*

	Case 1	**Case 2**	**Case 3**	**Case 4**
Number of signals	36	264	910	1520
Successfully categorised	36 (100 %)	239 (90.5 %)	745 (81.9 %)	1333 (87.7 %)
Change from the 1st att.	*10 (+38.5 %)*	*110 (+85.3 %)*	*39 (+5.5 %)*	*250 (+23.1 %)*
Failed categorisation	0	25 (9.5 %)	165 (18.1 %)	187 (12.3 %)
Change from the 1st att.	*-10 (-100 %)*	*-110 (-81.5 %)*	*-39 (-19.1 %)*	*-250 (-57.2 %)*
Signals with alt. sub-group	2 (5.6 %)	12 (4.5 %)	55 (6.0 %)	68 (4.5 %)
Change from the 1st att.	*0*	*10 (+500 %)*	*2 (+3.8 %)*	*-17 (-25.0 %)*

Concerning the number and percentage of successfully categorised signals, the results shown in the Table 6.4 were close to expected: every signal of case 1 was successfully given categories, and cases 2 and 4 had got high improvements, case 2 from accuracy of 48.9 % to 90.5 % and case 4 from 71.3 % to 87.7 %. Also case 3 had improved slightly from 77.6 % to 81.9 %, but as the failures it had at the first attempt were too difficult to interpret and thus to take into account, the improvement was not bigger than that.

Surprisingly, the percentages of signals with an alternating sub-group did not change that much. For case 1 the percentage was the same 5.6 % as at the first attempt and for case 3 the number of signals grew only by 2, from 53 (5.8 %) to 55 (6.0 %). The biggest change was for the signals of case 2: the amount grew from 2 (0.8 %) to 12 (4.5 %). Unlike for the other signals lists, for case 4 the number of signals with an alternating sub-group decreased – from 85 (5.6 %) to 68 (4.5 %). These small changes prove that the added new keywords were rationally chosen, meaning the categoriser can be taught, when done carefully and reasonably, more effective without causing too much unwanted extra categorisation.

7. RESULTS AND DISCUSSION

In total three goals were set for this thesis. The first one was to find out what kind of challenges the variations in vessel alerts and alert systems cause for developing an intelligent alert system customisable for variable vessel types. The second one was to suggest which vessel types should be first focused on when developing an intelligent alert system from the perspective of variations of alerts and alert systems and effort needed to customise the alert system. Finally, the third goal was to give simple examples of how to customise an intelligent alert system for various vessel types and vessels. In this chapter it is reviewed how these goals were reached, as the main results of this work are discussed and evaluated.

In section 7.1, the main results provided in the sections 5.3 and 6.3 are summarised and the research questions introduced in the section 1.3 are answered. The results are discussed and goal achievement is evaluated in sub-chapter 7.2.

7.1 Summarised results

In the literature part of this work, i.e. in the chapters 2 and 4, it was first realised that there is a vast amount of different maritime vessel types which differ in numerous ways, such as in size, machinery and equipment, operational purpose, etc. This meant a challenging starting point for the rest of this work, as the huge variety of different vessels would supposedly mean a huge variety of different vessel alerts and alert systems. On the other hand, finding out the principles of the basic structure, functions and machinery of a vessel helped to understand what actually happens on board. Later on, this knowledge helped to carry out the interviews as more relevant questions could be prepared and the interviewer could better discuss the concerning themes with the interviewees.

It was also noticed that there are many rules and regulations in the maritime industry and ship building, aiming to standardise systems and actions on board vessels, at least in some level. These rules and regulations are mainly set by the IMO and the various classification societies. However, the rules are very general and do not dig into details. For instance, regulations in the SOLAS and in CSs' rules say only what kind of features the systems must have and how they should be build. Regarding alert systems this means, for instance, that alerts have to be indicated in certain places, the system should be built fail-safe and some certain processes and incidents, e.g. closing or opening a watertight door, should cause an alarm. More detailed guidance how alert systems should be implemented, e.g. how alerts should be displayed, prioritised or identified, are covered in two IMO documents, the CAI and BAM. But since the more detailed guidance is given in the IMO codes that are not forceful directives but recommending publications, the maritime regulations do not really standardise alert systems that much and therefore they are not a guarantee for similarities between alerts and alert systems. Thus, data about variations between alerts and alert systems cannot be derived from the rules and regulations.

The knowledge gathered in the literature review was utilised in the executed interviews in which the practical variations in alert systems between various vessel types and vessels were studied. The aim was to get an answer to the first research question of this thesis, i.e. ‘How do alerts and alert systems variate between different maritime vessel types, vessels and alert system suppliers’ products?’ Based on the literature review, the hypothesis was that the alert system variations depend on the vessels’ complexity and level of automation: the more complex the vessel type is and the more there is automation onboard, the more the alerts and alert systems variate between different vessels of that type.

The interview results proved that hypothesis, as alert systems on simple vessel types, such as tugs, cargo ships and tankers were seen somewhat similar: the basic functions and operations of those ships are quite standard and so are the basic alerts. Variations in more detailed level, however, were seen alert system-dependent, which led to the other part of the first research question: ‘How do alert systems variate between alert system suppliers’ products?’ For this the interviews gave quite superficial answers. According to them, basic principles and user interfaces are somewhat similar between products of common suppliers’, such as Wärtsilä, ABB and Kongsberg. Bigger differences were experienced to be in the intelligence of systems and in what kind of data they provide to the operators. Most of the systems were seen quite un-intelligent as they did not have any features like alert prioritising or suppression in them. Also, the provided data variated as some systems gave more detailed alert descriptions and others only series of numbers, which had to be checked physically from the alerting equipment itself. But as said earlier, the interviews did not give very detailed knowledge about this.

One goal of this thesis was to suggest which vessel types should be first focused on when developing an intelligent alert system. This was to be done so that the vessel types with smallest variations in alerts and alert systems are suggested to be focused on first and the ones with the biggest last. Based on the interviews and with the help of literature, the vessel types could be arranged so that vessel types with smaller variations, and thus the ones to be focused on first, would be tugs, oil tankers, containers and general cargo ships. Vessel types with bigger variations would be all types of vessels with numerous auxiliary systems and functions and a high level of automation. These kinds of vessels are especially passenger cruise ships with covering services and high level accommodation offered for the people on board, and certain types of off-shore vessels with dynamic positioning systems, such as FPSOs and drilling vessels. In addition, vessels that are dealing with LNG, that has to be stored in very cold temperature, can be very complex and have a high level of automation with numerous measuring points. These kinds of vessels are for instance all LNG-powered vessels and LNG carriers. All of these complex types should be focused on last. In between the two extremes are left vessel types such as Ro-Ro ships, fishing vessels, chemical tankers and off-shore service vessels.

Also an alternating roadmap for the development work was proposed in the interviews. It suggests that the simplest vessel types should be passed over as an intelligent alert system would be rather useless on them. Therefore, a good starting point could be some semi-complex vessel type that would not be very difficult to start with but that would also have a bit higher level of automation on it, ensuring that an intelligent alert system would also benefit the crew. These kinds of vessel types are for instance off-shore service vessels and chemical tankers and based on the alternating roadmap suggestion they should be focused on first. Of these, the off-shore service vessels are normally equipped with modern systems, such as dynamic positioning system, causing a lot of alarms. Chemical tankers, on the other hand, have numerous measuring points due to often toxic cargo they are carrying and therefore very many alarm points in their alert systems.

The two alternative roadmap suggestions are summarised in Table 7.1.

Table 7.1. *Roadmap suggestions for development of an intelligent alert system.*

Phase of development	Suggestion 1	Suggestion 2
Initial phase	Tugs, oil tankers, containers, general cargo ships	Off-shore service vessels, ice-breakers, chemical carriers
Intermediate phase	Ro-Ro vessels, icebreakers, chemical carriers, off-shore service vessels, fishing vessels	Ro-Ro vessels, fishing vessels
Final phase	Cruise ships, Complex off-shore vessels (e.g. FPSO), LNG-powered vessels, LNG tankers	Cruise ships, complex off-shore vessels (e.g. FPSO), LNG-powered vessels, LNG tankers

In addition to the suggestions presented in the Table 7.1, the interviews proposed to do a market review for trying to find out if there are some big series of vessels in which the vessels might be very similar to each other. However, this did not fit in the scope of this thesis but could be a recommendable approach for possible future work.

The second research question of this thesis concerned the challenges the variations in alerts and alert systems cause for developing an intelligent alert system for various vessel types. This can be answered with the help of knowledge gained in the literature review and in the executed interviews and by comparing different alert signal lists with each other. The principle is that for an alert system to be intelligent it should include features, such as alarm rationalising, prioritising, shelving, grouping, etc. In order to achieve these kinds of functionalities, each alert's importance for the vessel operation should somehow be evaluated. This could be done, for instance, by grouping alerts based on the vessel resource they are originating from, e.g. cooling system alerts into their own group, propulsion system alerts into their own, and so on. In these groups the significance of each alert for their resource could be further considered.

However, when developing an intelligent alert system for various vessel types, this grouping is the phase for which the variations in alerts and alert systems cause challenges. As the interview results indicated, alert signal data can variate a lot in different vessels and systems and the variations can also often be very random. Comparing some different alert signal lists confirmed this, as for instance alert sources like propulsion system and main engine might be written as 'propulsion system' and 'main engine' in some lists while in some other lists they are abbreviated as 'PS' and 'ME'. As usually equipment and system names are shortened in signal lists, grouping hundreds or even thousands of alerts from existing lists is challenging: doing it automatically can be difficult and prone to errors and manually it takes a lot of time and effort.

The third research question dealt with alert system customisation, as the goal was to provide examples how to optimally customise an intelligent alert system for various vessel types. In this case optimal means the best possible outcome with as little work as possible. After analysing the earlier results of this thesis and the answers to the first two research question, an alert signal list categoriser tool was developed in MS Excel. The categoriser classifies alert signals into categories based on the functions and equipment they originate from. The SFI Group System's groups were utilised when defining the signal categories, as it is internationally a quite widely used system that has already divided the vessel equipment and functions into groups. The categoriser was meant to do as automatically as possible the alert grouping, which is needed when developing an intelligent alert system. It was also developed so that users can easily update it to make it 'smarter' and to get more precise results. After development, the categoriser was tested with couple of alert signal lists and it proved to be quite effective and easily updatable.

7.2 Discussion

Interviews turned out to be an effective way of gathering knowledge as a lot of things about vessels and their operations was learnt. It was found useful to be able to ask for clarifying questions. The interview answers described things from the operational point of view and not very much in detailed level. Thus answering the first research question was challenging. However, with the help of other information sources, i.e. literature review and some real-life alert lists, it could be done.

To improve the reliability of the results, more interviews could have been done. This was however seen unnecessary as the gathered data was sufficient for reaching the goals of this thesis; the amount of interview data was relatively small but the answers were convergent.

Even though the gathered knowledge about the variations in vessel alerts and alert systems did not go into hard details, the first two goals of this thesis were reached. The challenges the variations cause for developing an intelligent alert system for various vessel types could be analysed. This analysis could also be utilised in the later work of this thesis. A roadmap for the development of an intelligent alert system for various vessel types was meaningfully suggested, this included also an alternating version with reasonable arguments.

The developed signal list categoriser proved to work well and to be easily used and updated with the executed tests. Already at the first attempt it provided good results and at the second attempt the categorising was very effective even for lists with some hundreds of signals. In addition, it was tested with a list of 3000 signals and proved to handle also a data of that amount. Still, as tests were done with limited amount of signal lists, more testing with new alert lists would be useful, as the categorisation accuracy would be further improved.

Of course, the implemented tests showed some issues too. For instance, SFI sub-groups given to the categorised signals should not be blindly trusted as there are hundreds of them in the SFI system. Instead, they should be considered more as suggestions that are good to have for possible further use. Also, the user should be careful when adding new keywords into the keyword dataset as irrelevant keywords can cause unwanted, alternating SFI sub-group suggestions for the signals. Finally, in addition to these, the categoriser Excel workbook proved to be occasionally quite unstable. For instance, sometimes the programme crashed or command buttons might stop working. Therefore it is recommendable to have a functioning back-up copy of the Excel workbook.

On the whole, the third goal of this thesis can be considered well reached. The aim was to provide a simple example of how to take the variations in alert signals into account when customising an intelligent alert system and that was clearly done. As the developed categoriser is a functioning prototype that can also easily be updated in the future it is more than a simple example. As also the first two goals were reached, the results of this thesis can be evaluated satisfying.

8. CONCLUSION AND FUTURE WORK

In modern maritime vessel alert systems the amount of alarm signals can be massive. This is caused on the one hand by the easiness and cheapness of adding new I/Os to the systems and on the other by the high level of automation on modern maritime vessels. Very big amount of alert signals in a system often causes problems with alert management. These appear e.g. in alarm flooding situations during which the amount of alarms is too high for the crew to handle them quickly and precisely enough. As the trend in the maritime industry is to go towards more and more automated vessels and the goal is to introduce autonomous and remotely operated vessels in the near future, the alert system problems caused by huge amounts of alert signals will only get worse. At the same time, more and more is demanded from the systems, as the data they provide need to be more detailed and precise. This results in the need of developing more intelligent alert systems with sophisticated alarm management features.

This chapter sums up this thesis. A conclusion summarising the objectives, methods and results of this work is given in sub-chapter 8.1. In addition, suggestions for future work are given in the last section of this thesis, i.e. in sub-chapter 8.2.

8.1 Conclusion

The objective of this thesis was to help with the development of an intelligent vessel alert system. The purpose was to find out what kind of variations there are in alerts and alert systems between different maritime vessel types and vessels, what kind of challenges they cause for the development of an intelligent alert system and how they could be overcome. To reach this purpose, two research methods, interview study and text classification, were utilised. Before utilising them, a literature review about basic maritime vessel functions and machinery, various maritime vessel types, standards and regulations and automation and alert systems was done to gain the needed knowledge.

After the literature part, the first applied section was the implemented interview study in which maritime experts were interviewed. According to the interviews, basic alert and alert system variations of various vessel types are caused by the differences in structures, machinery and equipment, operational purpose and amount of passengers. Thus, e.g., a very complex cruise ship with a high level of automation and many human lives on board has a complicated alert system. A contradictory example could be a conventional tug with low level of automation, no passengers and therefore a much simpler alert system. More detailed variations were seen dependent on the alert system products. The basic principles and operational interfaces of different solutions were experienced rather similar.

However, the things important for development of an intelligent alert system, such as data presentation and alert tagging, were seen differing widely and somewhat randomly. A good example of these variations is different ways of abbreviating equipment names in alert descriptions. For instance, instrument air system might be written in such ways as ‘IA system’, ‘instr. air system’, ‘working air system’ or ‘WA system’ in different alert lists. These variations make developing an intelligent alert system more time taking and arduous: because of the variations, it is difficult to automatically group alerts based on their origin and manually done it takes a lot of time and effort. Grouping the alerts has an important role in the design of an intelligent alert system, meaning that the caused challenges are significant.

One of the goals of this study was also to suggest a roadmap for the development of an intelligent alert system. It was to be such that the vessel types with the least alert and alert system variations would be focused on first and the types with the most variations last. This was to be done in order to have little challenges with the variations at the beginning of the development. As a result, two suggestions were given. The first proposed to focus first on the simplest vessel types such as tugs and general cargo vessels. After them the focus should be on vessels with a little higher level of automation, such as chemical tankers and Ro-Ro vessels. At last, the focus should be put on the most complex vessels, such as cruise ships, LNG-powered vessels and more developed off-shore vessels.

The alternating suggestion recommended to leave out the simplest vessel types out as they would not benefit a much of an intelligent alert system and start from vessel types that are a bit more complicated, but that would still be manageable with the variations. These kind of vessels could be for instance chemical tankers and off-shore service vessels. After them could come e.g. Ro-Ro vessels and icebreakers and other vessels with same kind of automation level. Finally, the focus could be put on the most complicated vessels.

In the later section of the applied part of this thesis, an Excel solution was developed to act as an example how the challenges with the alert variations could be overcome. In this development text classification and SFI Group System’s grouping methods and help of real-life vessel alert lists were utilised. The solution, called signal list categoriser, groups differently described alert signals of various alert signal lists into groups based on the vessel system and equipment they originate from. For instance, the signal list categoriser would recognise abbreviations such as ‘azm thr’, ‘azi thr’ or ‘azim thrstr’ in different alerts to mean ‘azimuth thruster’ and that way it could group all those alerts into SFI main group *4 – Ship equipment* and into sub-group *404 – Side thrusters*. In the performed tests the signal list categoriser provided good results and proved to be easily updated and improved.

8.2 Future work

To get a more detailed picture of the variations in vessel alerts and alert systems more research would be needed. An effective way could be collecting a large amount of alert signal list data and making comparison with it. This would, however, be a very demanding task as there are tens of thousands of maritime vessels in the global merchant fleet, meaning the amount of data would be gigantic. Also, acquiring signal lists is very difficult, as they are classified information owned by different shipping companies and shipyards. Nevertheless, especially with a good data source, this would be an approach to think of if the task was to do detailed comparison.

Doing more expert interviews could help getting more detailed knowledge of the variations, at least up to some point. Especially, by interviewing people from companies supplying automation and alert systems could give ideas how things are implemented in detailed level in different alert system products. One possibility could also be studying user manuals of various automation and alert systems and trying to find out and to conclude more detailed information in them. These kind of approaches, however, would not be possible for a study that is done as an assignment for a company that is a competitor for these automation and alert system providers.

More ideas of how to customise the alert system for various vessel types might be found by studying how things are done in other industrial areas, e.g. in process and airline industries. Compared to the maritime industry, much more work to rationalise alert systems has been done in the process industry, as the two international standards, *ANSI/ISA-18.2,* and *EEMUA 191*, and the many research articles mentioned in the section 1.2 indicate. This is also something that came up in the interviews, as same kind of intelligent alarm management features that power plant alert systems have were hoped for vessel alert systems too. In the airline industry, on the other hand, all the engineering has to be done very punctually to minimise accidents, which cause serious risks for human lives and the environment. As a result, there could be something that could be utilised in developing an intelligent maritime vessel alert system.

The developed signal list categoriser was done with the help of only limited amount of signal lists, meaning it might not work properly for signal lists with uncommon alerts. The categoriser, however, was done so that it is easily updatable and therefore this limitation would be overcome by adding more keywords from new signal lists. In addition to this, more tests could help improving the current keyword dataset by finding out if there are unnecessary keywords making the categoriser to suggest many incorrect SFI subgroups.

The signal list categoriser could also be improved by enhancing its VBA code. Now the categoriser classifies the signals into main groups based on the first keyword it finds, which, in the most cases, gives a correct category as the signal descriptions tend to start with a textual data that addresses the source of the alert. However, some different kind of approach that would, for instance, evaluate the found keywords and categorise the signals based on the likeliest ones might eventually be better. This kind of feature that would evaluate the found keywords would also be helpful when the user judges if the categorisation has been correct or not.

One possible area to be studied is advanced machine learning algorithms, such as support vector machines and neural networks. A more intelligent and a self-learning signal grouping solution utilising these algorithms could be more effective when it comes to taking the alert variations into account. Programming a solution utilising these would not have been a simple example and thus would have been out of the scope of this thesis. In possible future work these could, however, be reasonable approaches.

Some other things that were not studied in this thesis are many existing text categorisation programmes and applications. These might also be helpful in the alert system customisation and therefore an area of interest in possible future work.

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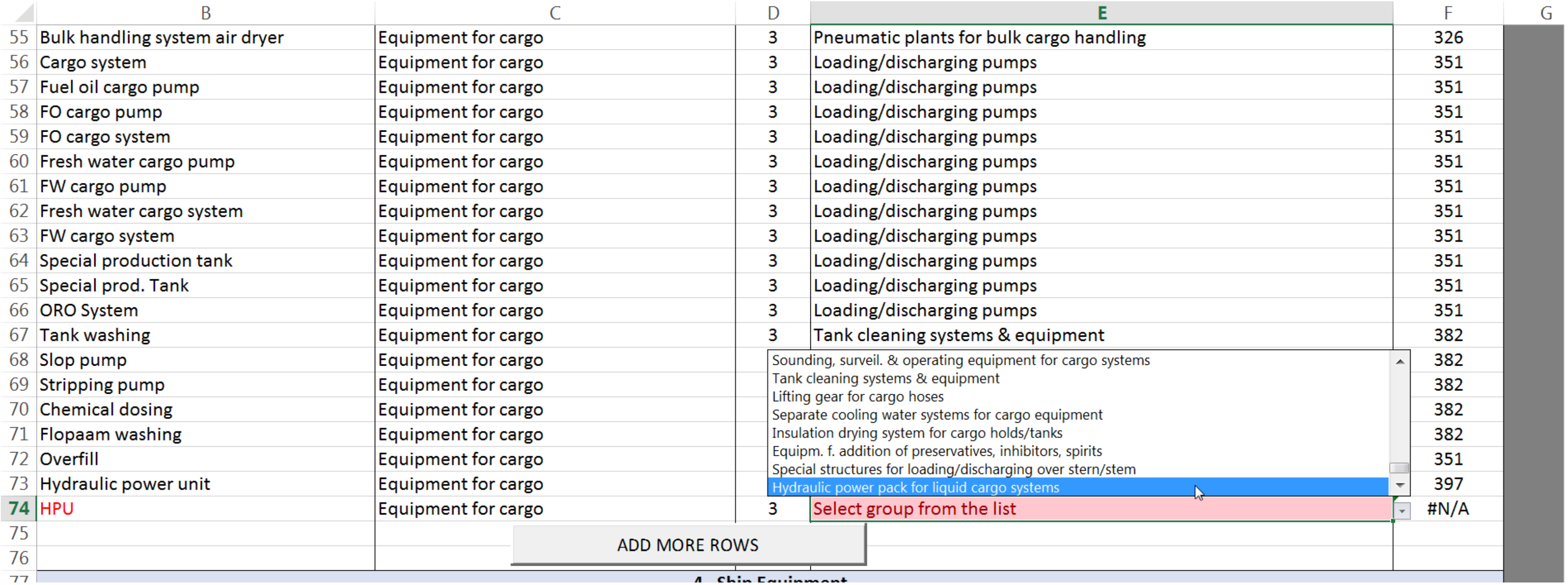
APPENDIX A: INTERVIEW QUESTION FRAME (IN FINNISH)

The interview question frame utilised in the interviews is presented in the following. The text is in Finnish, as it was the language of the carried out interviews.

1. Haastateltavan ammatilliset taustatiedot ja kokemus eri laivatyypeistä
    - Koulutus, työhistoria, nykyiset työtehtävät?
    - Alustyypit, joilla työskennellyt?
        - Ajankohdat?
        - Minkälaisissa työtehtävissä?
        - Mistä alustyypistä eniten kokemusta, mistä vähiten?
2. Haastateltavan kokemus laiva-automaatio- ja hälytysjärjestelmistä
    - Minkä eri järjestelmätoimittajien järjestelmistä kokemusta?
        - Mistä eniten, mistä vähiten?
        - Millä laivoilla mikäkin järjestelmä oli?
    - Kokemukset eri toimittajien järjestelmien eroavaisuuksista toisiinsa nähden?
        - Esimerkiksi hälytyskuvaukset ja –tagit?
    - Onko alustyyppien ja eri laitetoimittajien järjestelmien välillä yhteyttä? Toisin sanoen, käytetäänkö tietyillä alustyypeillä yleensä tiettyjä hälytysjärjestelmiä?
3. Vaihtelevuudet eri alustyyppien ja alusten välillä
    - Miten hälytysten määrä/esiintymistiheys vaihtelee alustyypeittäin? Ovatko jotkut alustyypit selkeästi ”hälytysherkempiä” kuin jotkut toiset?
        - Miten samat asiat vaihtelevat saman alustyypin eri alusten välillä?
    - Vaihtelevatko hälytysten prioriteettitasot alustyypeittäin? Toisin sanoen, onko joillain laivoilla korkeampiprioriteettisia hälytyksiä paljon ja joillain toisilla pelkästään matalaprioriteettisia?
        - Sama kysymys saman alustyypin eri aluksille
    - Ovatko jonkun alustyypin laivat yleensä hyvin samankaltaisia keskenään, ts. samat osajärjestelmät ja laitteistot yms. yleensä käytössä?
4. Marssijärjestys älykkään hälytysjärjestelmän kehittämiselle
    - Minkä alustyypin/alustyyppien alukset ovat keskenään eniten samankaltaisia, minkä eniten erilaisia?
        - Pätevätkö samankaltaisuudet ja eroavaisuudet myös hälytyksiin? Miten?

APPENDIX B: SIGNAL LIST CATEGORISER SCREENSHOTS

This Appendix contains screenshots of the signal list categoriser.



	B	C	D	E	F	G
55	Bulk handling system air dryer	Equipment for cargo	3	Pneumatic plants for bulk cargo handling	326	
56	Cargo system	Equipment for cargo	3	Loading/discharging pumps	351	
57	Fuel oil cargo pump	Equipment for cargo	3	Loading/discharging pumps	351	
58	FO cargo pump	Equipment for cargo	3	Loading/discharging pumps	351	
59	FO cargo system	Equipment for cargo	3	Loading/discharging pumps	351	
60	Fresh water cargo pump	Equipment for cargo	3	Loading/discharging pumps	351	
61	FW cargo pump	Equipment for cargo	3	Loading/discharging pumps	351	
62	Fresh water cargo system	Equipment for cargo	3	Loading/discharging pumps	351	
63	FW cargo system	Equipment for cargo	3	Loading/discharging pumps	351	
64	Special production tank	Equipment for cargo	3	Loading/discharging pumps	351	
65	Special prod. Tank	Equipment for cargo	3	Loading/discharging pumps	351	
66	ORO System	Equipment for cargo	3	Loading/discharging pumps	351	
67	Tank washing	Equipment for cargo	3	Tank cleaning systems & equipment	382	
68	Slop pump	Equipment for cargo			382	
69	Stripping pump	Equipment for cargo			382	
70	Chemical dosing	Equipment for cargo			382	
71	Flopaam washing	Equipment for cargo			382	
72	Overfill	Equipment for cargo			351	
73	Hydraulic power unit	Equipment for cargo			397	
74	HPU	Equipment for cargo	3	Select group from the list	#N/A	
75						
76						

Figure B.1. *Example of adding a new keyword to the Keywords sheet*

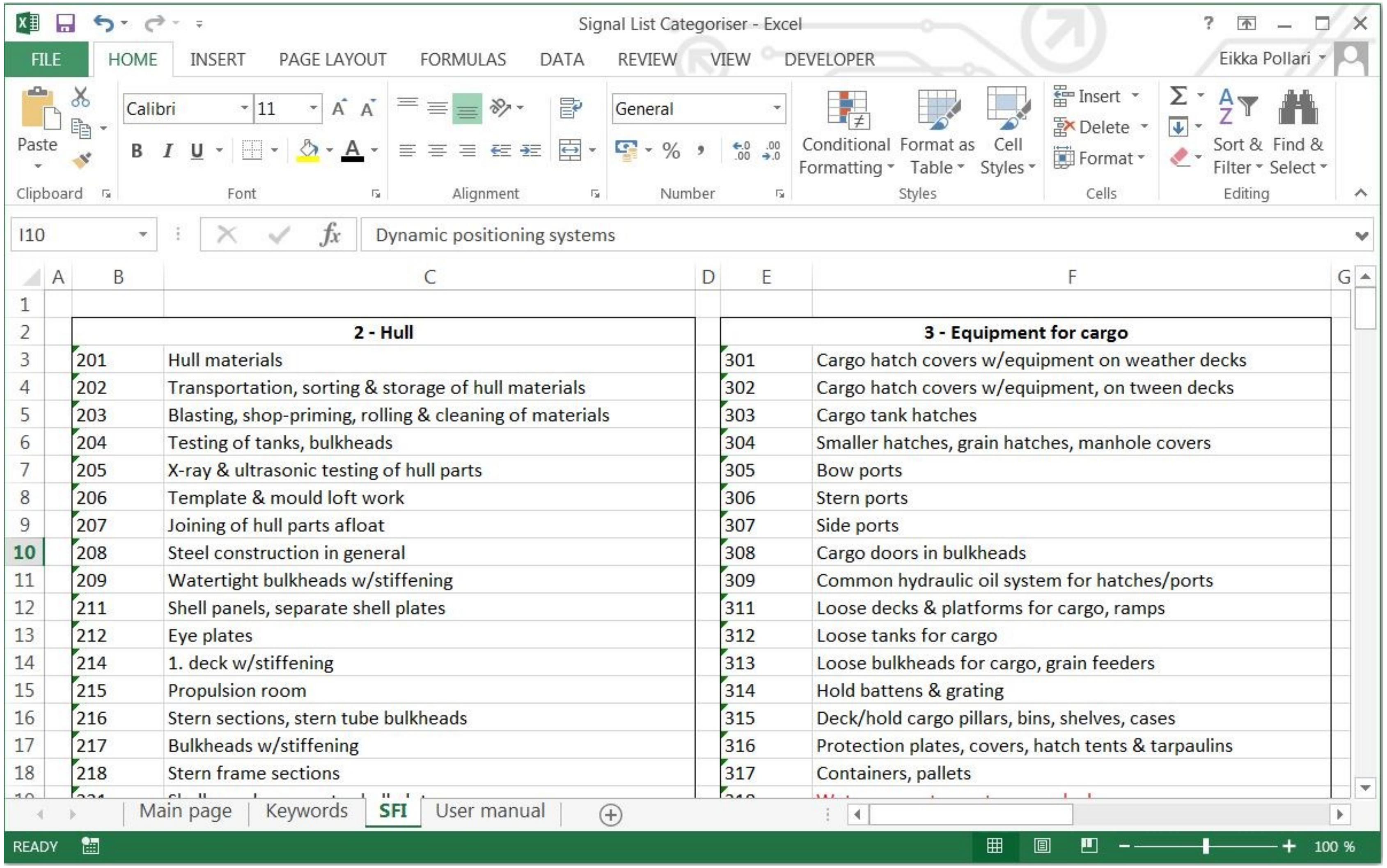


Figure B.2. *SFI sheet of the signal list categoriser workbook.*

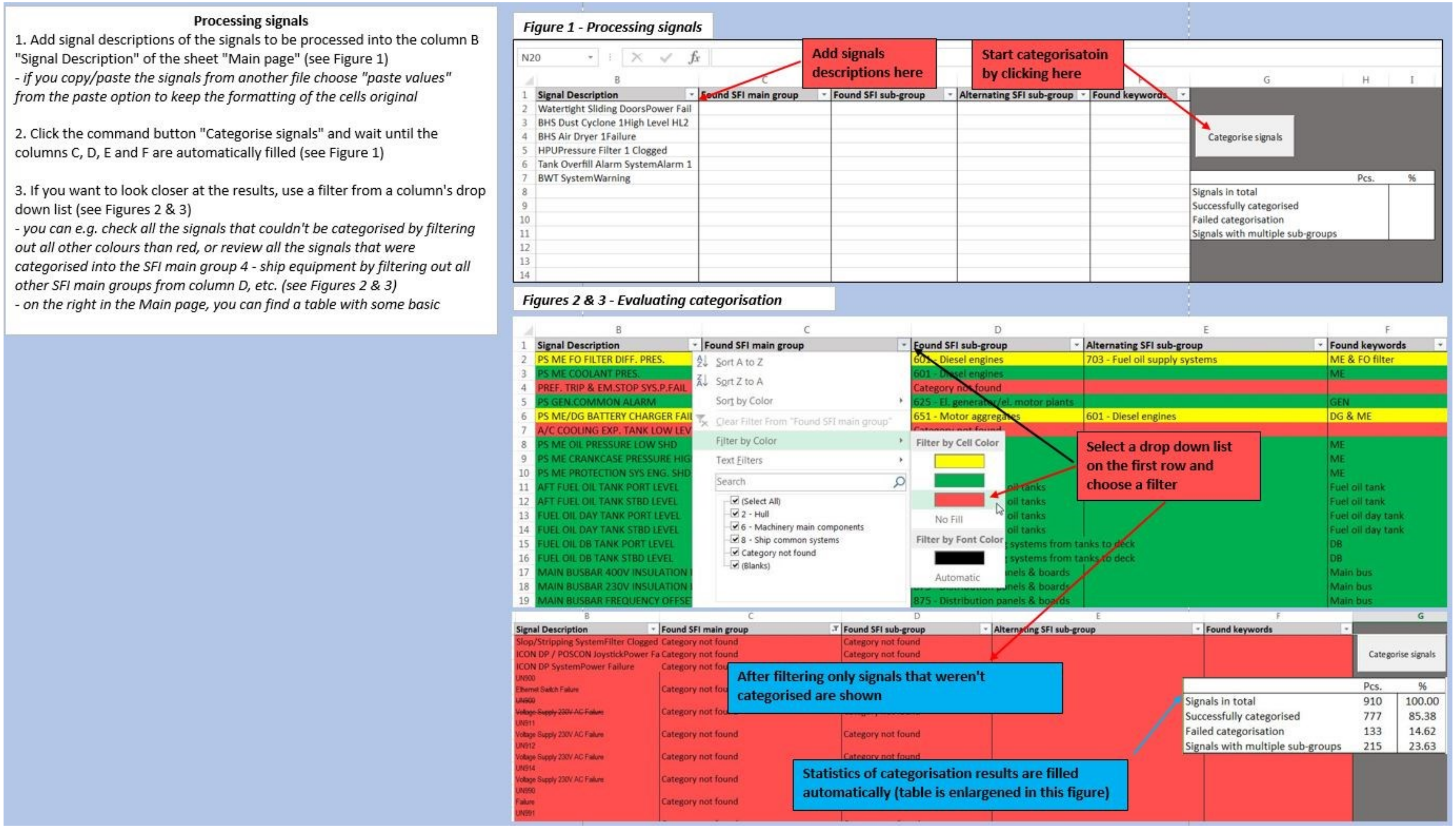


Figure B.3. *User manual 1/3.*

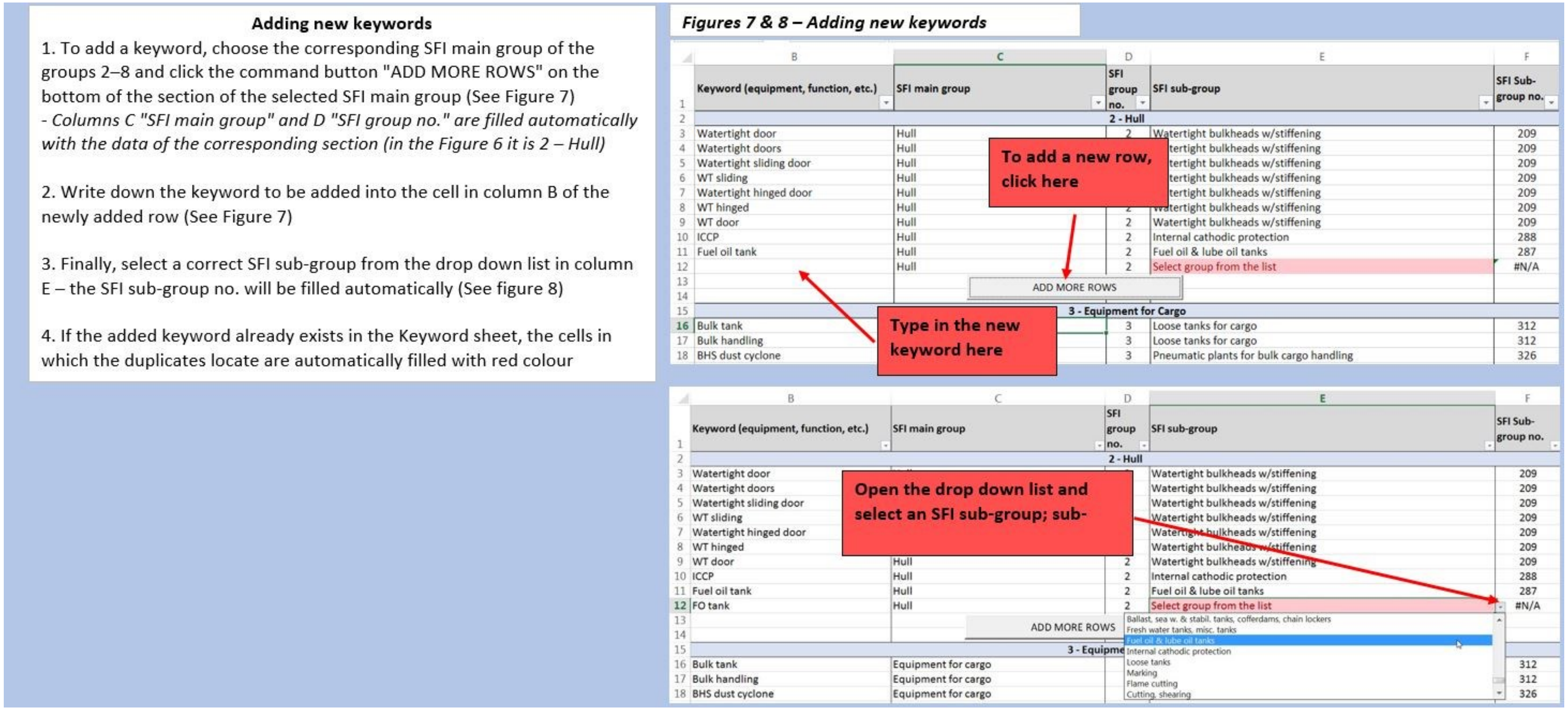


Figure B.4. *User manual 2/3.*

Figure B.5. *User manual 3/3.*